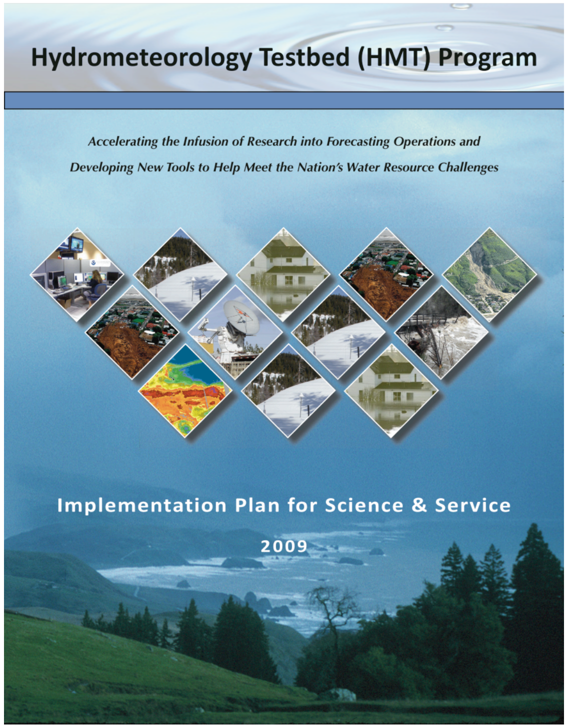
An Overview of the Hydrometeorology Testbed

Tim Schneider
HMT Program Manager
http://hmt.noaa.gov/



Outline

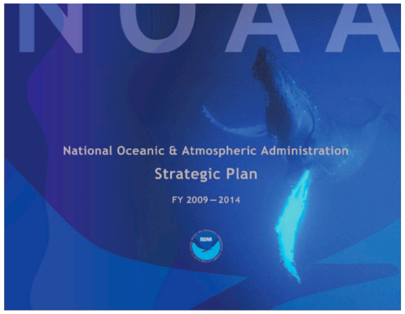
I. An Overview of HMT
   - Motivation
   - The "who, what, why, when & where" of HMT

II. A Closer Look at QPF
   - From requirements to a new national performance measure: An end-to-end story

Part I.

An Overview of HMT

- Motivation
- The “who, what, why, when & where” of HMT



NOAA's Weather & Water Strategic Goals

OUTCOMES

- Reduced loss of life, injury, and damage to the economy
- Better, quicker, and more valuable weather and water information to support improved decisions
- Increased customer satisfaction with weather and water information and services

OBJECTIVES

- Increase lead-time and accuracy for weather and water warnings and forecasts
- Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events
- Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (federal, state, local, tribal), private, and academic partnerships
- Increase development, application, and transition of advanced science and technology to operations and services
- Integrate local, regional, and global observation systems into NOAA's weather and water services to increase the collaboration between NOAA and external environmental partners
- Reduce uncertainty associated with weather and water forecasts and assessments
- Enhance environmental literacy and improve understanding, value, and use of weather and water information and services

NOAA Forecasts Water

The NWS STIP

NWS Organic Act: "…forecasting of weather, the issue of storm warnings, display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers…"

NOAA Inland Flood Forecasting and Warning Act: "…improve the capability to accurately forecast inland flooding, and conduct research, outreach, and education activities regarding the dangers and risks associated with inland flooding…"

A Five-Year Flashback

WHAT:

- *Cool-Season Quantitative Precipitation Forecasting Workshop*
- A meeting sponsored by the U.S. Weather Research Program brought together nearly 60 federal, private, and university scientists to develop a strategy to improve short-term coolseason QPF

WHEN:

- 2–5 February 2004

WHERE:

- Boulder, Colorado

CORE RECOMMENDATIONS:

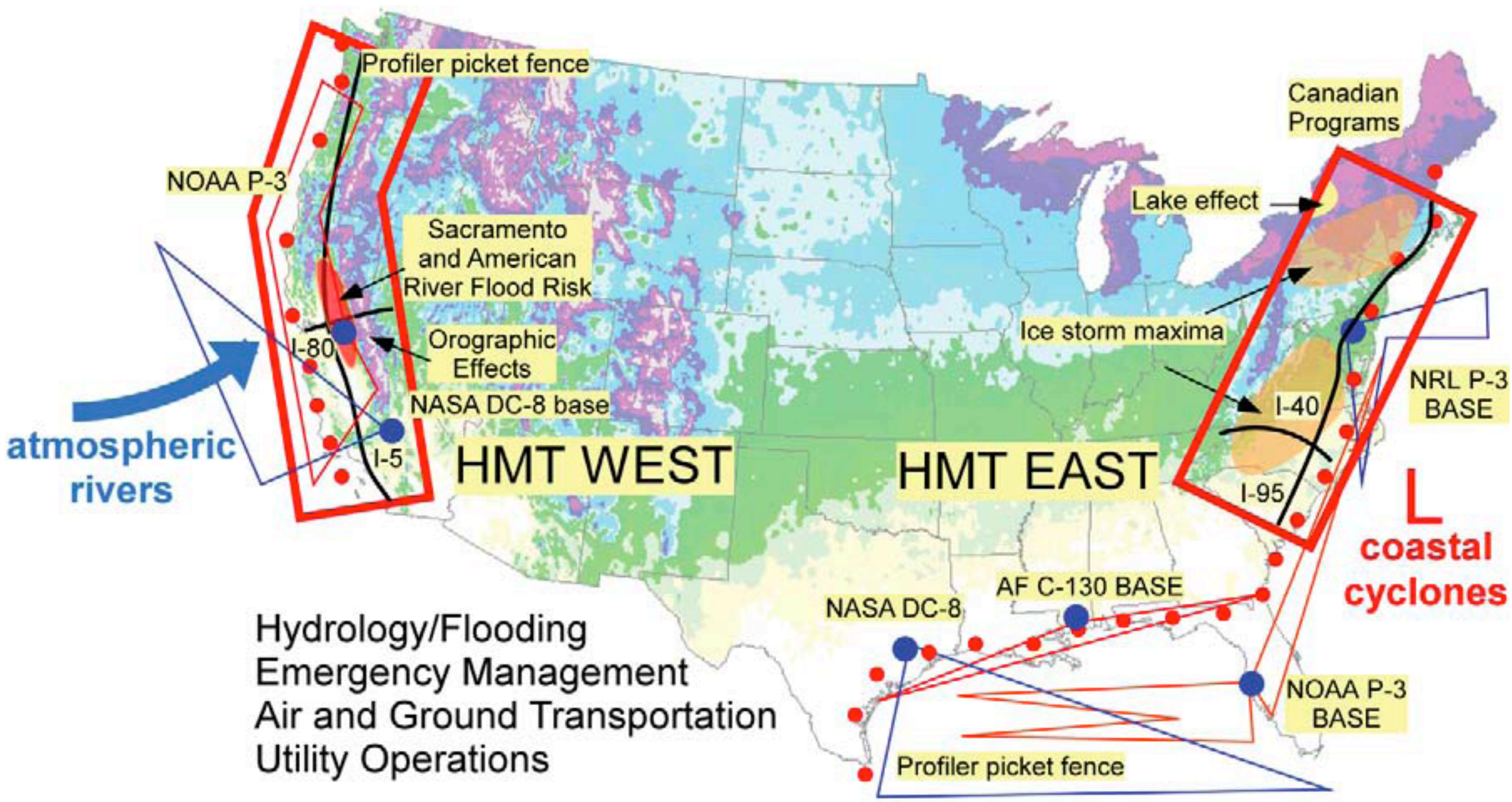
1. Establish a National Hydrometeorological Test-bed Approach
2. Develop Probabilistic Methods
3. Advance Mesoscale Data Assimilation and Modeling

Ralph, et. al., 2005 : "Improving Short-Term (0–48 h) Cool-Season Quantitative Precipitation Forecasting Recommendations from a USWRP Workshop", BAMS, November 2005, pp. 1619-1632

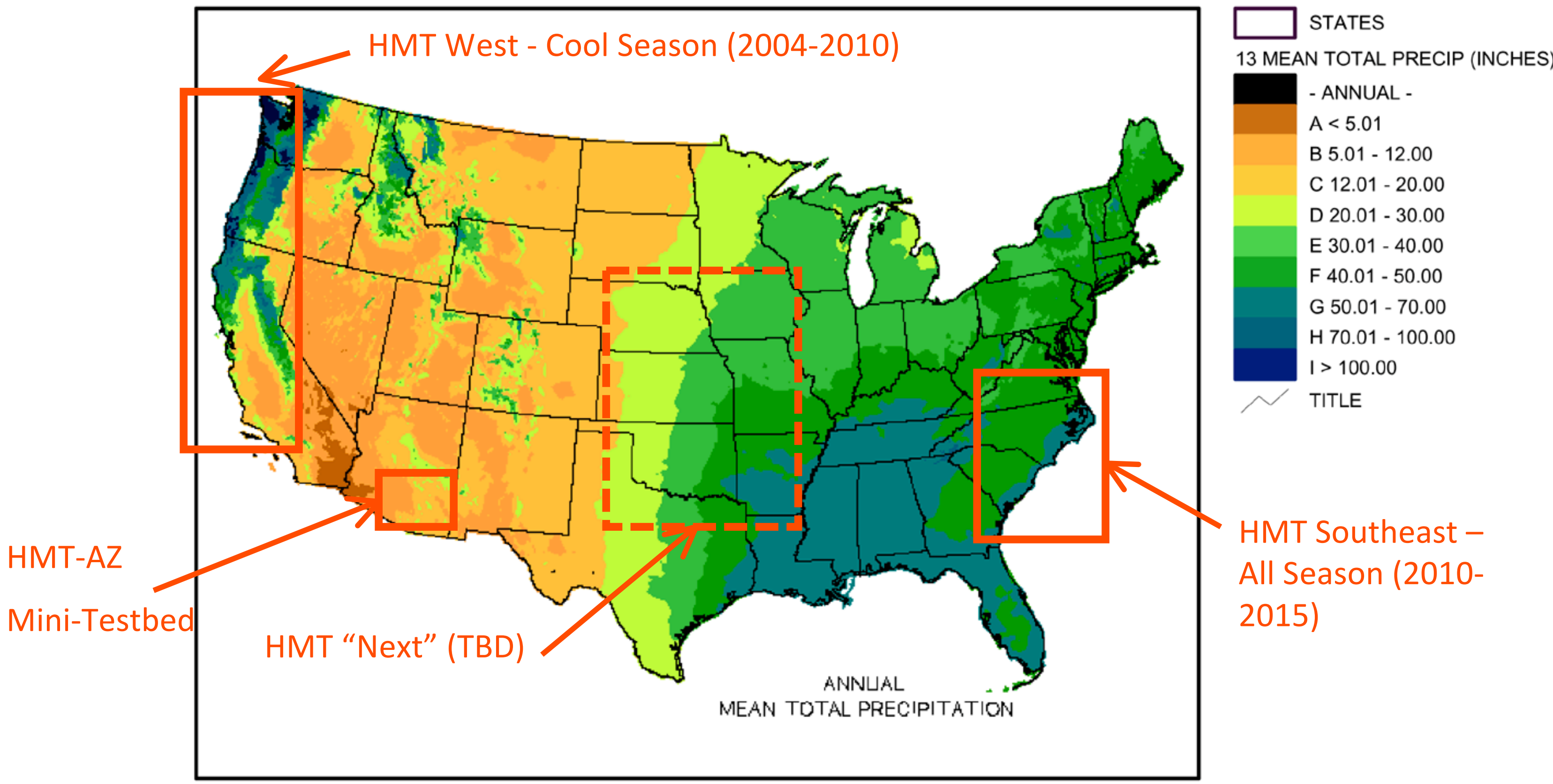
Table 1. Participants in the USWRP Cool-Season QPF workshop.	
James Arnold, NASA/Marshall Space Flight Center (MSFC)	Greg Poulos, UCAR/Atmospheric Technology Division (ATD)
Robert Atlas, NASA/Goddard Space Flight Center (GSFC)	Paul Pugner, U.S. Army Corp of Engineers
Stan Benjamin, NOAA/Forecast System Laboratory (FSL)	Marty Ralph, NOAA/ETL
Dave Caldwell, National Centers for Environmental Prediction (NCEP)	Roy Rasmussen, NCAR
Brian A. Colle, State University of New York (SUNY) at Stony Brook	Bob Rauber, University of Illinois at Urbana—Champaign
Edwin Danaher, NWS/NCEP/HPC	Pedro Restrepo, NWS Office of Hydrology
Russ Elsberry, Naval Postgraduate School	David Reynolds, NWS Forecast Office, San Francisco, CA
Gary Estes	Diana Roth, NOAA/CIRES
Bob Gall, NCAR	Steve Rutledge, Colorado State University
John Gaynor, USWRP Program Office	John Schaake, NOAA/NWS
Jim Giraytys, USWRP Integrated Program Office (IPO)	Tom Schlatter, NOAA/FSL
Rod Gonski, NWS, Raleigh, NC	David Schultz, CIMMS, and NOAA/NSSL
Jonathan Gourley, Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) National Severe Storms Laboratory (NSSL)	Paul Schultz, NOAA/FSL
Arthur Henkel, NOAA/River Forecast Center (RFC), Sacramento, CA	Mel Shapiro, NOAA
Mark Hjelmfelt, South Dakota School of Mines and Technology	Jim Steenburgh, University of Utah
Steve Hunter, U.S. Bureau of Reclamation	Andrew Stern, Mitretek Systems
Brian Jewett, University of Illinois at Urbana–Champaign	Ronald Stewart, McGill University
Pam Johnson, NCAR	Ed Szoke, NOAA/FSL, and Cooperative Institute for Research in the Atmosphere (CIRA)
David Jorgensen, NOAA/NSSL	Zoltan Toth, Environmental Modeling Center (EMC)
Matthew Kelsch, University Corporation for Atmospheric Research (UCAR)/Cooperative Program for Operational Meteorology, Education and Technology (COMET)	Steve Tracton, Office of Naval Research (ONR)
David Kingsmill, NOAA/CIRES	Jeff Trapp, Purdue University
Steven E. Koch, NOAA/FSL	Louis Uccellini, NOAA/NCEP
Ruby Leung, Pacific Northwest National Laboratory (PNNL)	Steve Vasiloff, NOAA/NSSL
Bill Mahoney, NCAR	Jeff Waldstreicher, NOAA/NWS
John Marwitz, Wyoming Weather, Inc.	Doug Wesley, UCAR/COMET
Douglas K. Miller, Naval Postgraduate School	Allen White, NOAA/ETL/CIRES
Rebecca Morss, NCAR	Gary A. Wick, NOAA/ETL
Paul J. Neiman, NOAA/Environmental Technology Laboratory (ETL)	James Wilczak, NOAA/ETL
Dave Parsons, NCAR	Milija Zupanski, Colorado State University
Paul Pisano, Federal Highway Administration	

Outline

Overarching Recommendation:
Use a National Hydrometeorological Testbed (HMT) approach to improve cool season QPF

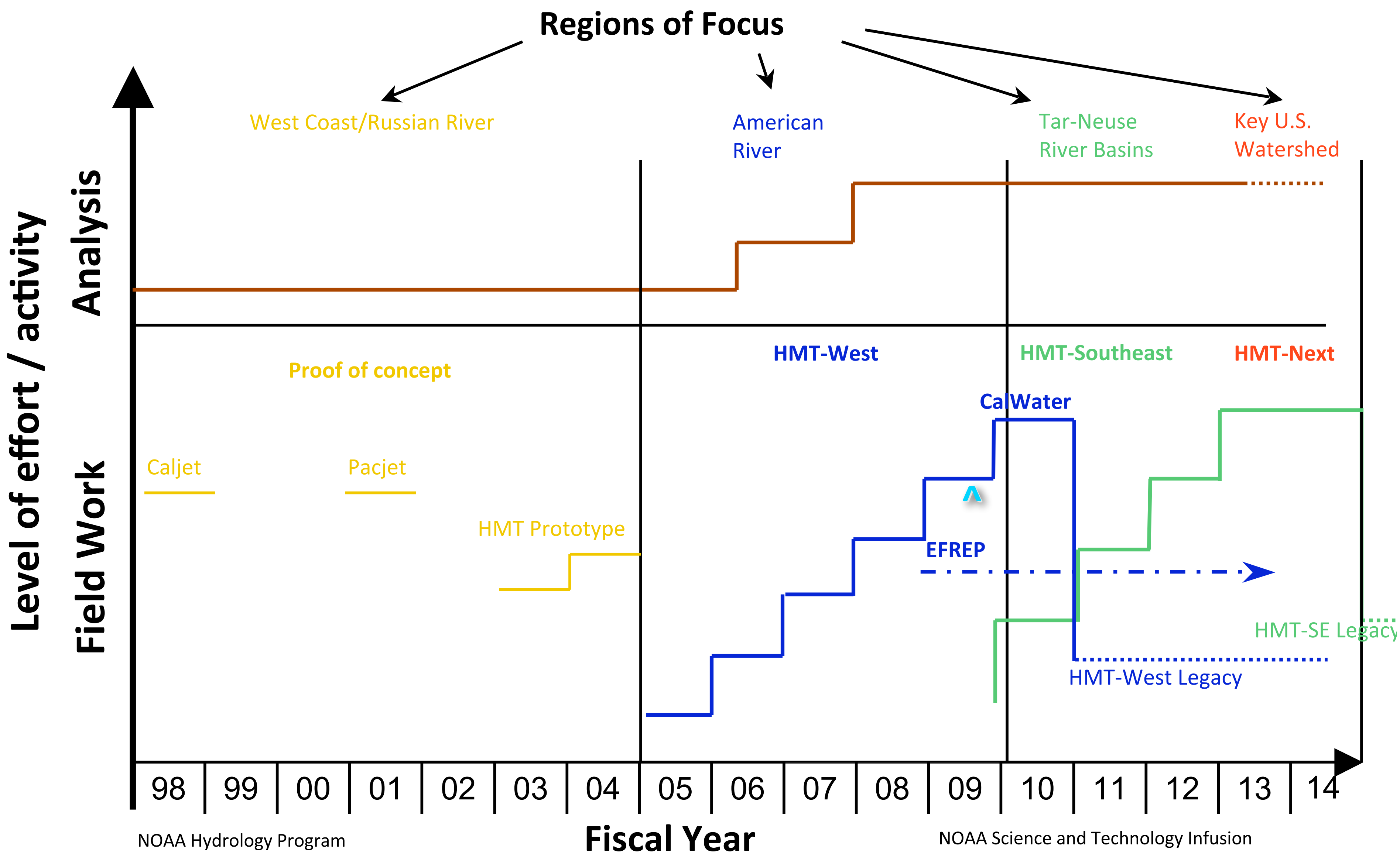


HMT: A National Testbed Strategy with Regional Implementation



- Dabberdt et. al., 2005: *Multifunctional Mesoscale Observing Networks*, BAMS, pp. 961-982
- Ralph et. al., 2005: *Improving Short-Term (0–48 h) Cool-Season Quantitative Precipitation Forecasting Recommendations from a USWRP Workshop*, BAMS, pp. 1619-1632

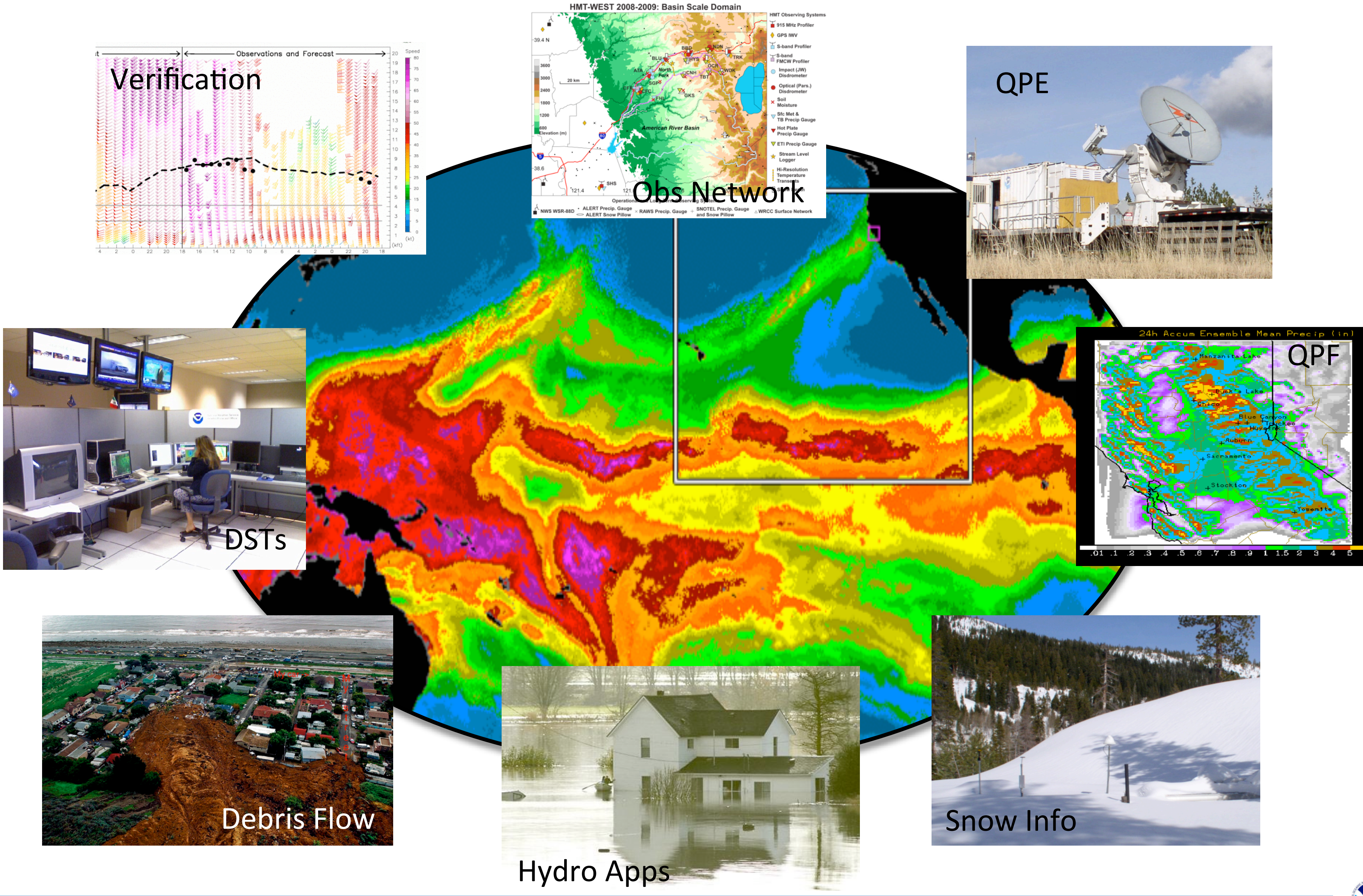
Hydrometeorology Testbed Timeline



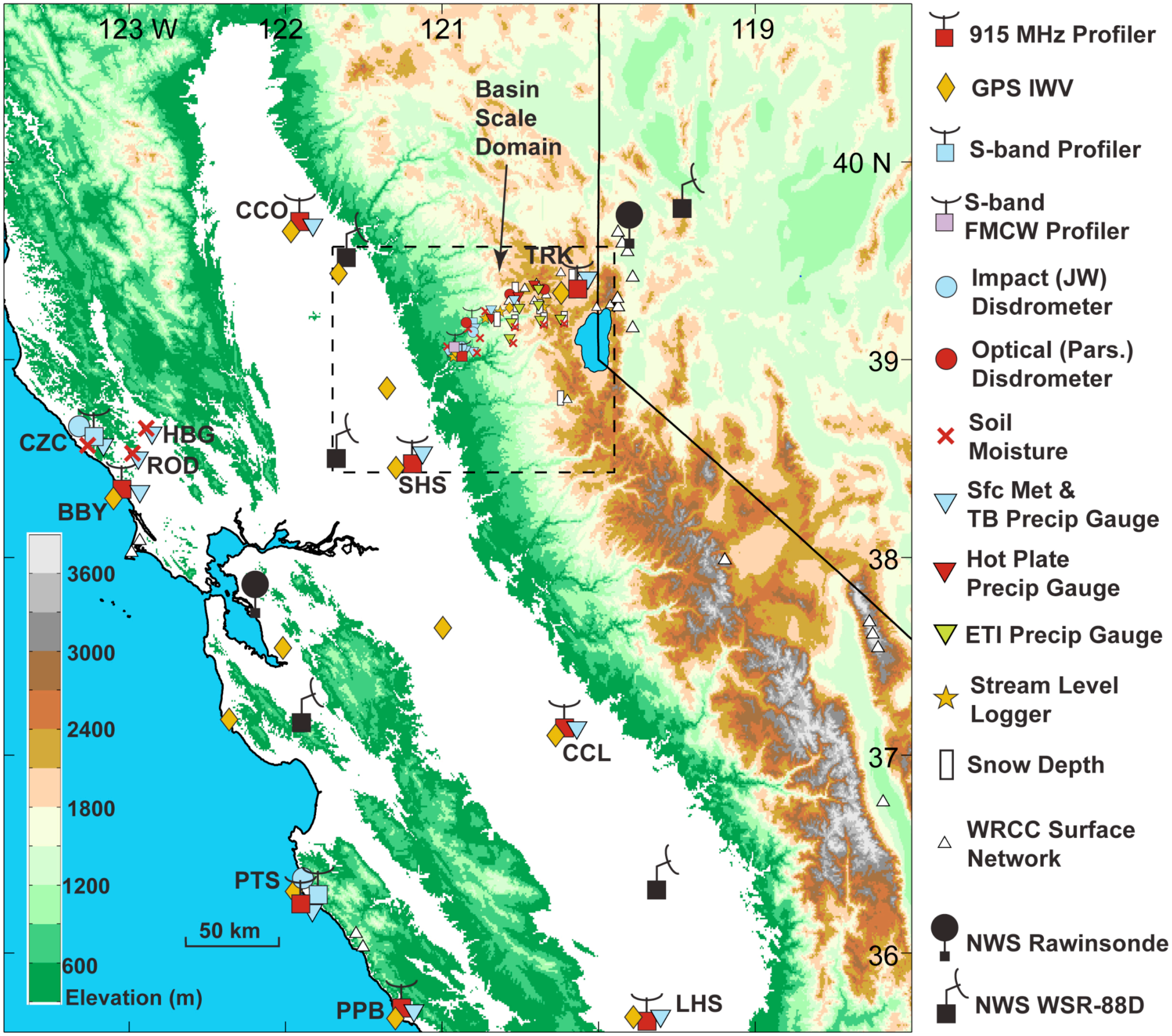
NOAA Hydrology Program
(Water Resources Data Assimilation)

NOAA Science and Technology Infusion Program
(Hydrometeorology Testbed)

HMT Major Activity Areas



HMT-WEST 2008-2009: Regional Scale Domain



Some Remarks on the Scope of HMT-SE

American River Basin

~1830 mi^2

North Fork: ~338 mi^2

Cool Season (Nov-Mar)

Tar-Pamlico River Basin

~5375 mi^2

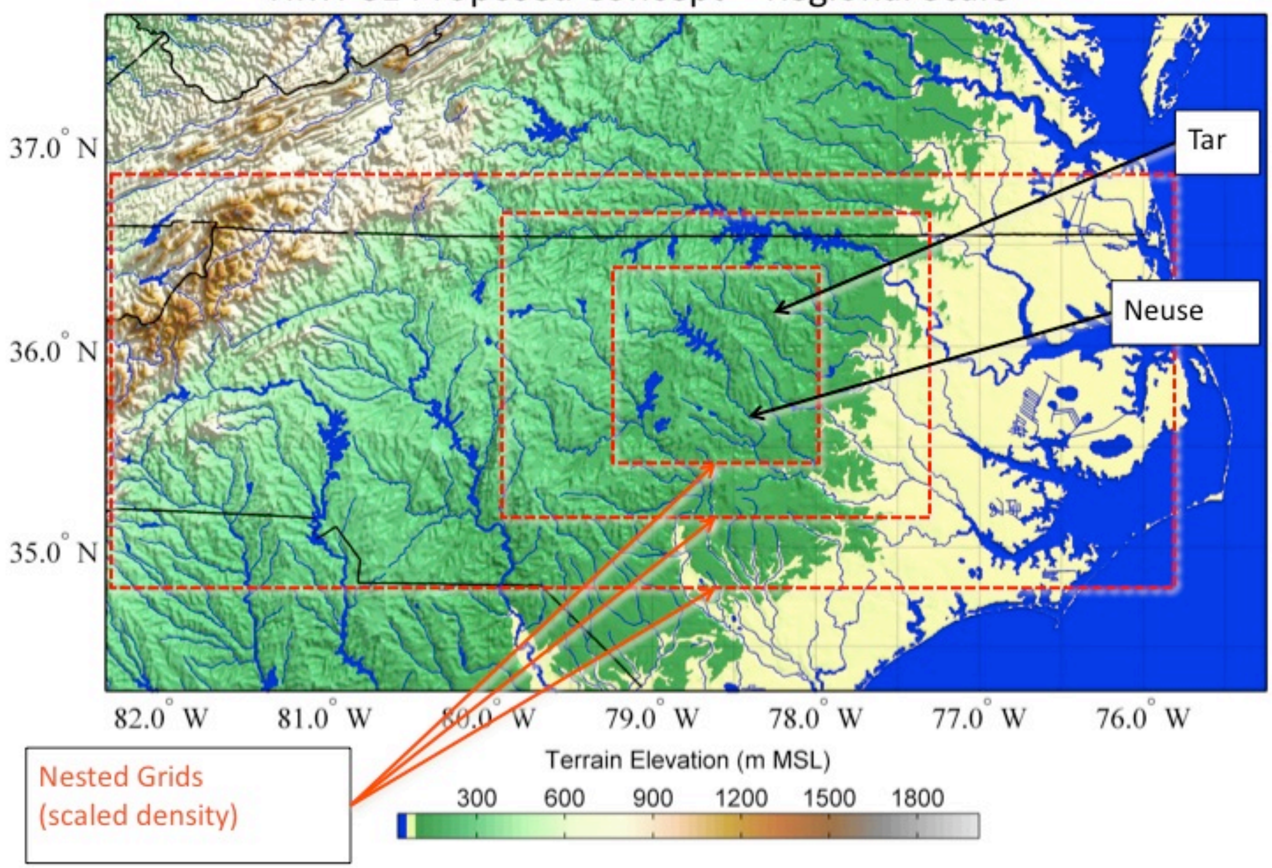
All season

Neuse River Basin

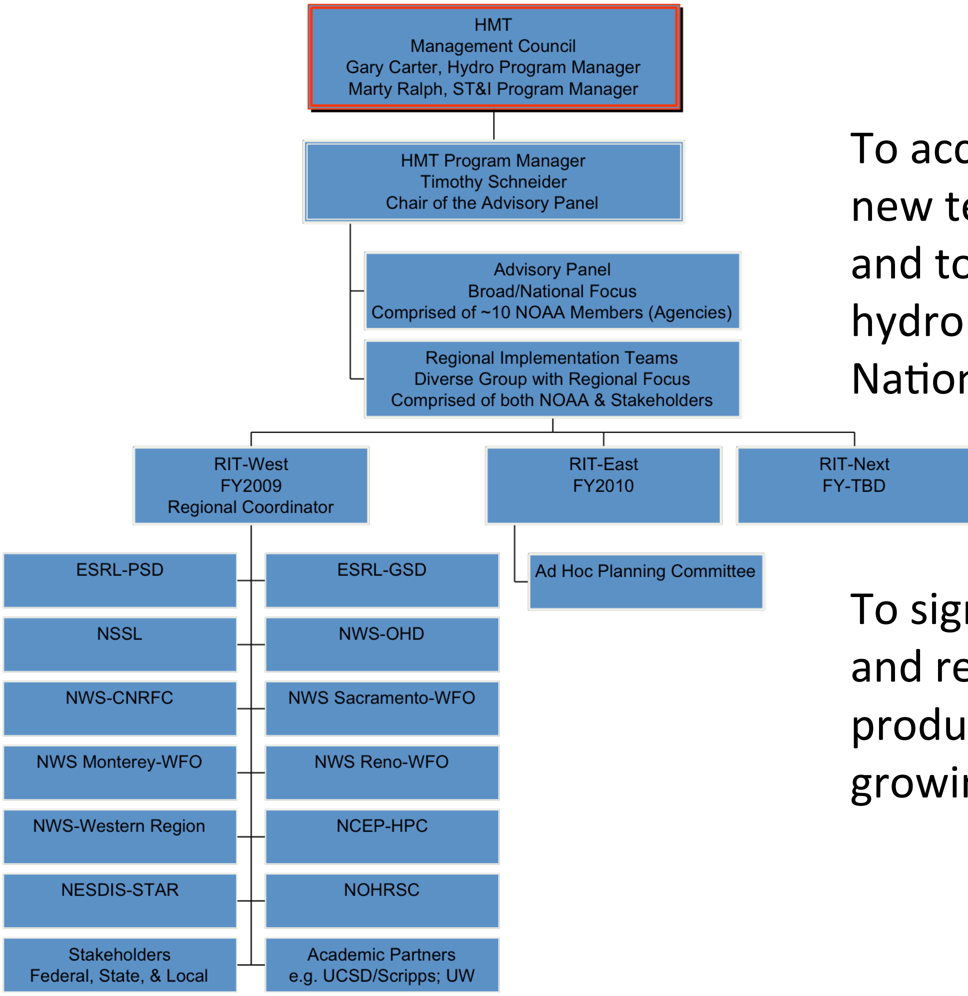
~6225 mi^2

All season

HMT-SE Proposed Concept – Regional Scale



Managing HMT
Building Partnerships

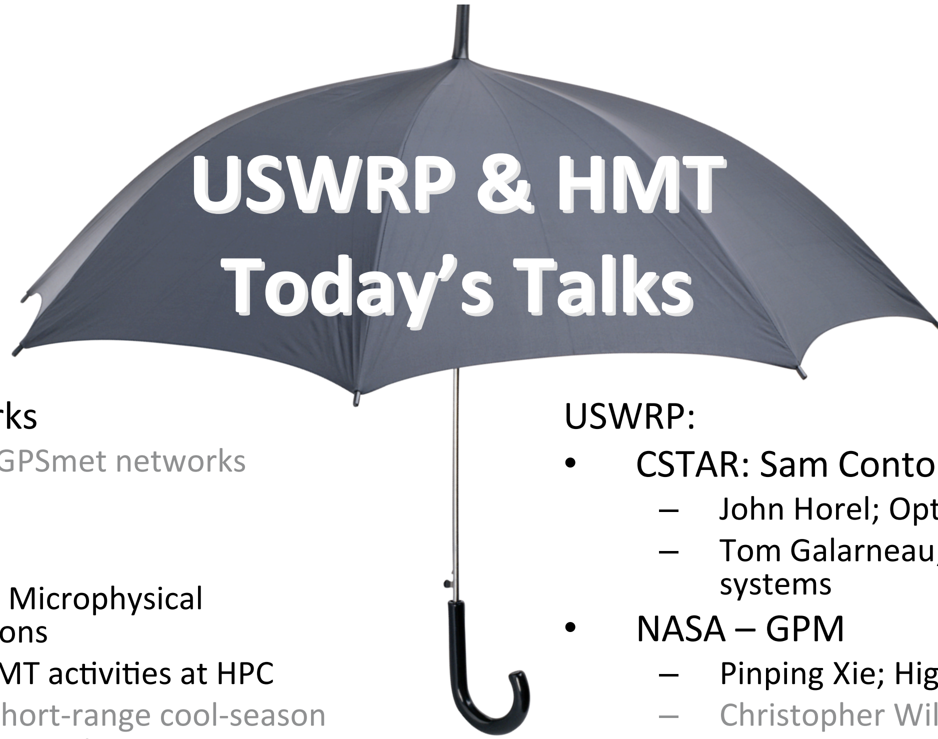


Mission (proposed)

To accelerate the research and development of new technologies, models, and scientific results and to enhance their infusion into the daily hydrometeorological forecasting operations of the National Weather Service

Vision (proposed)

To significantly increase the accuracy (verifiability) and reliability of NOAA's hydrometeorological products and services to meet the Nation's growing demands for water resource information



- Observing Networks
  - Seth Gutman; GPSmet networks
- QPE
- QPF
  - Isidora Jankov; Microphysical parameterizations
  - Ed Danaher; HMT activities at HPC
  - Huiling Yuan; Short-range cool-season precipitation forecasts
- Snow Information
  - Allen White; Snow level performance measures
- Hydrologic Applications
- Debris Flow
- Decision Support Tools
  - Woody Roberts; ALPS
  - Paul Neiman; AR Flux Tool
- Verification
  - Ed Tollerud; QPF verification

USWRP:

- CSTAR: Sam Contorno; Overview
  - John Horel; Optimal surface networks
  - Tom Galarneau; Warm-season precipitation systems
- NASA – GPM
  - Pinping Xie; High-resolution global precip.
  - Christopher Williams; Retrievals of DSDs
- DTC:
  - Barb Brown; Joint HMT-DTC efforts

R2O

- FFMP
- PARTI

Legacy

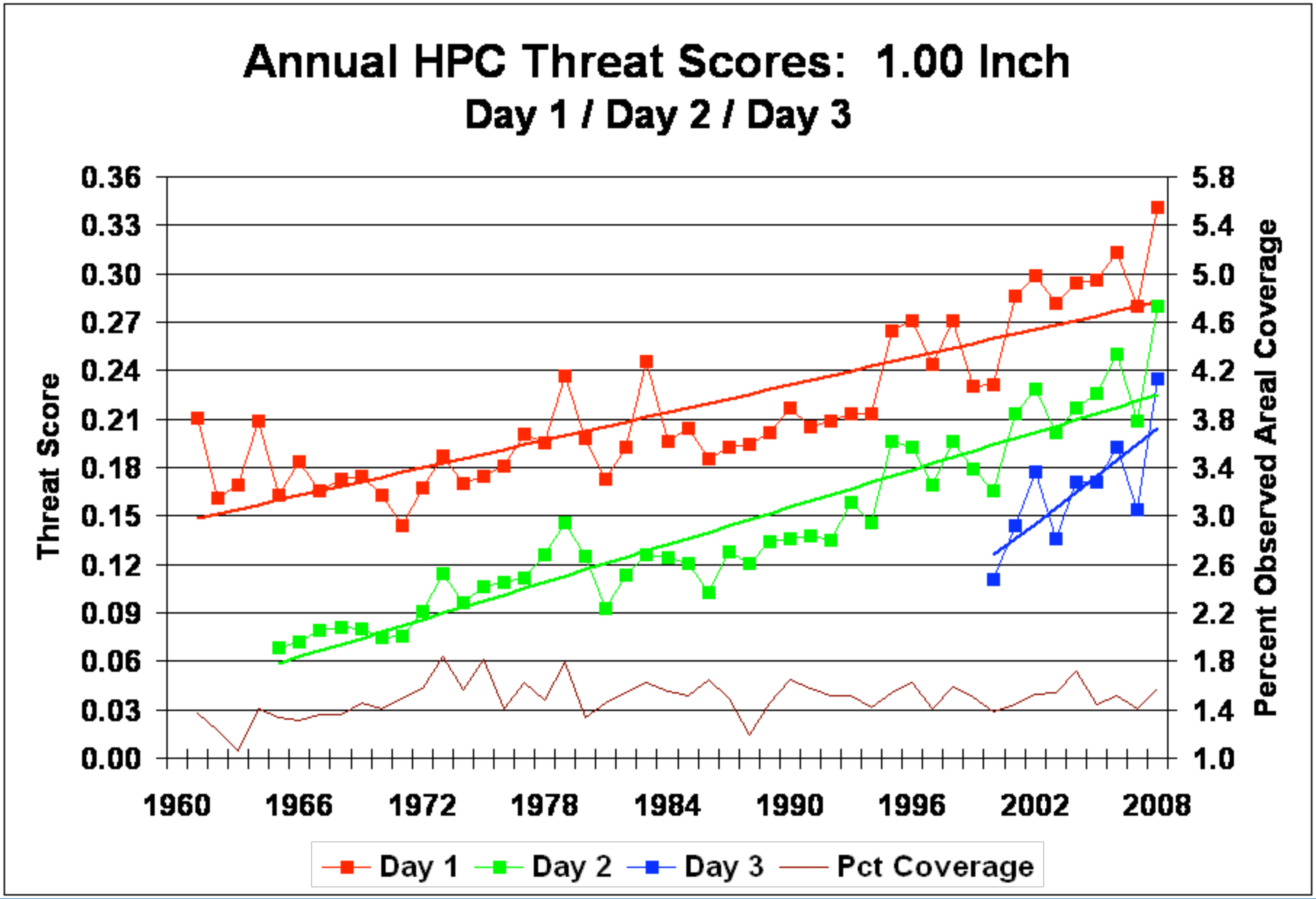
- EFREP (Legacy)
- CalWater

Part II.

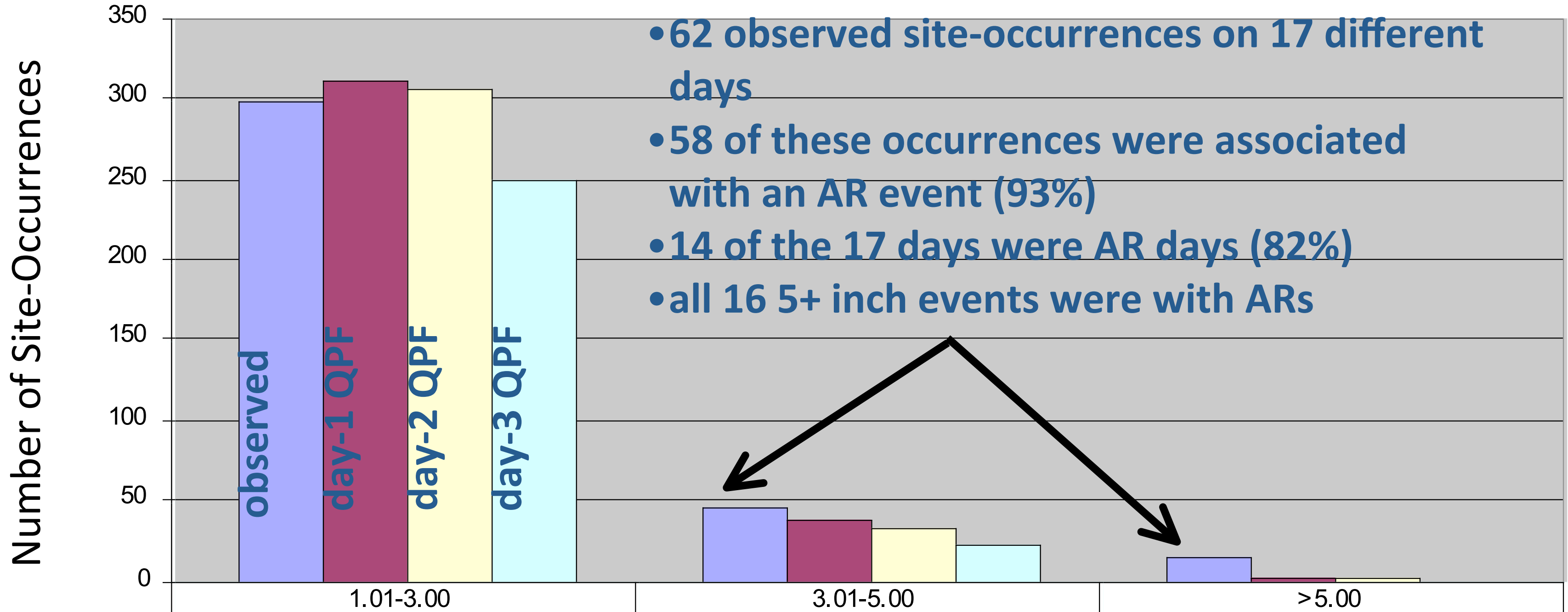
A Closer Look at QPF…

- From requirements to a new national performance measure: An end-to-end story

QPF is improving…



But, we're still missing the big ones

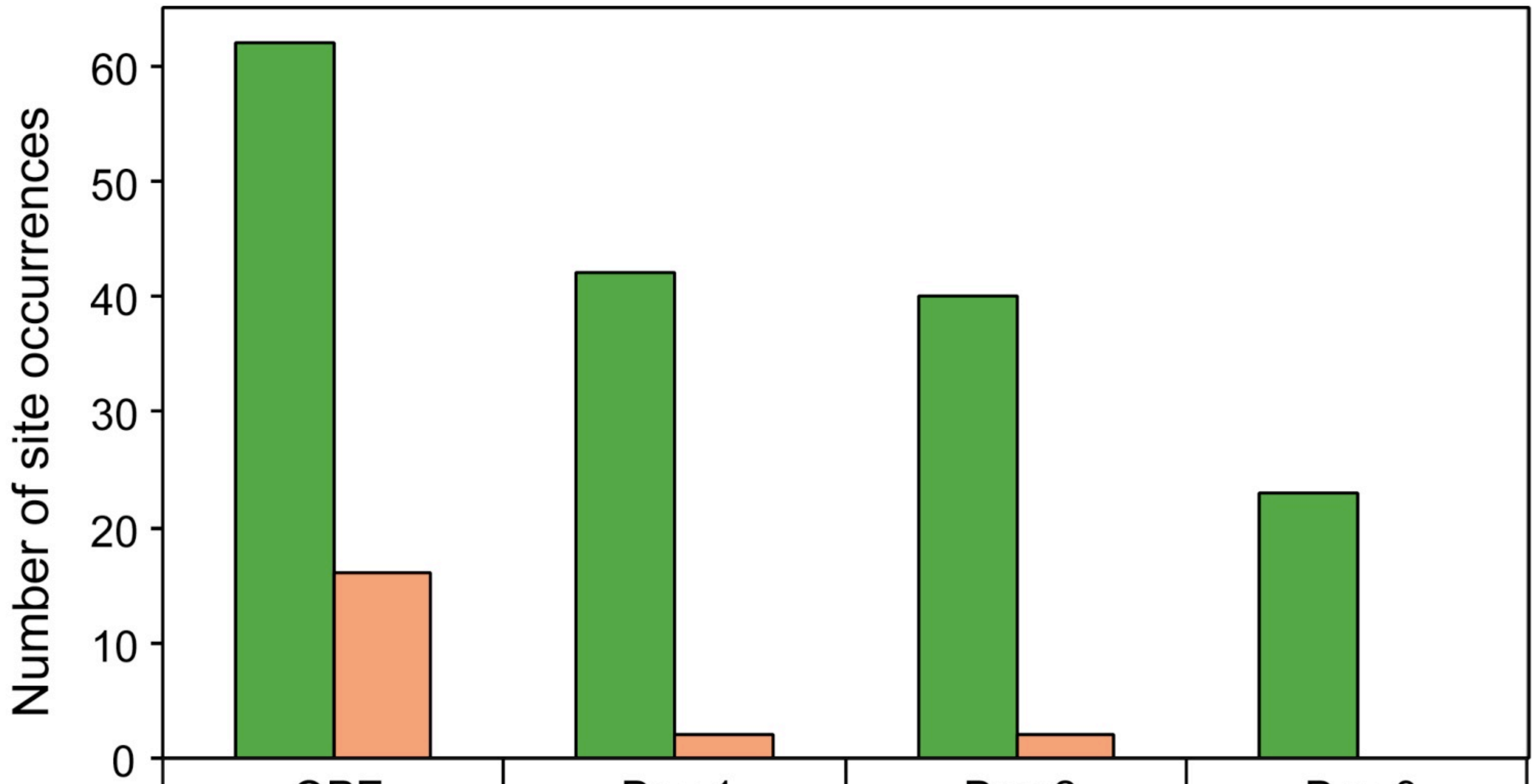


	1.01-3.00	3.01-5.00	>5.00
Observed	300	46	16
Day-1 QPF	311	39	2
Day-2 QPF	308	34	2
Day-3 QPF	250	24	0

24-h accumulation (inches)

- Modest precip events (<3"/day): Best QPF performance days 1 and 2
- Heavy precip events (3-5"/day): Significantly under-forecast
- Extreme precip events (>5"/day): Practically un-forecasted

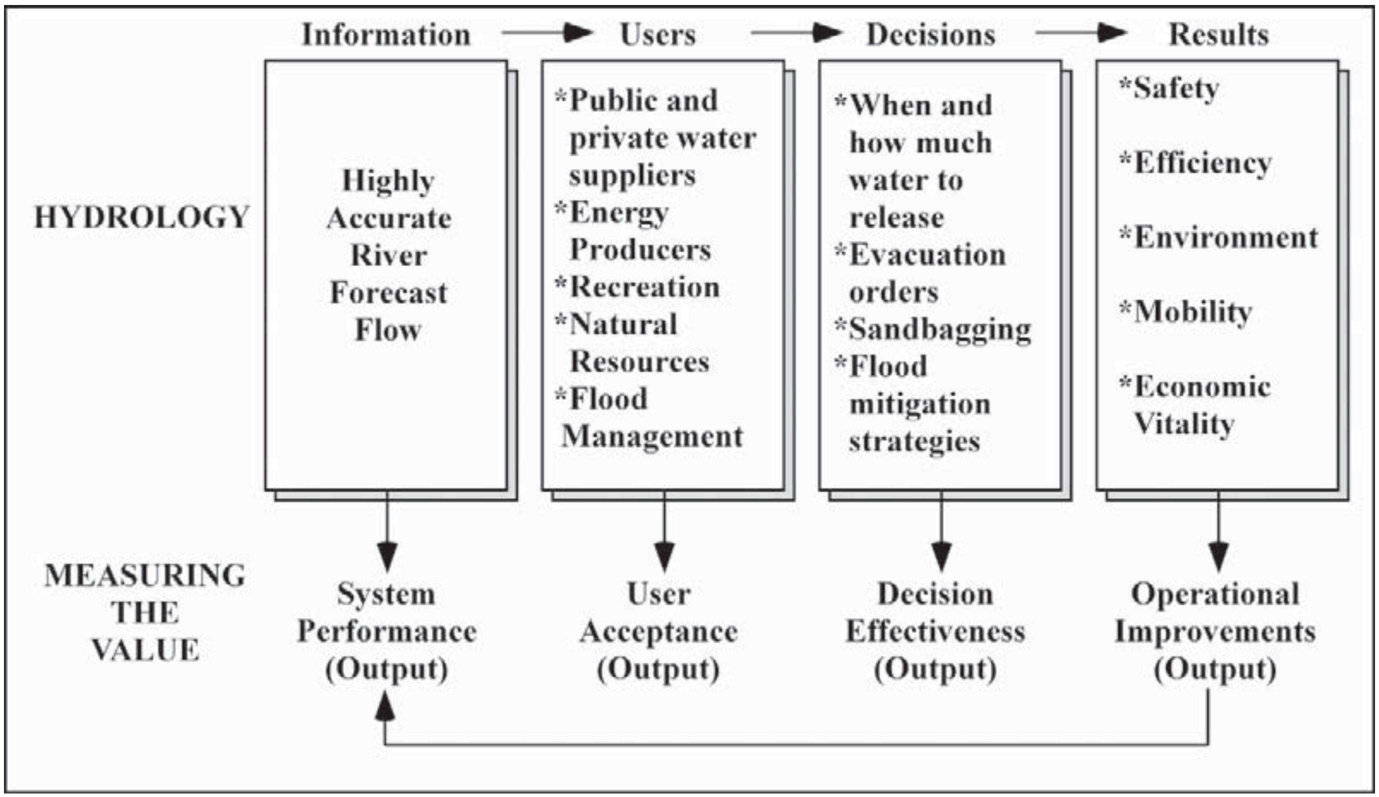
Observed and predicted site occurrences > 3” and > 5”



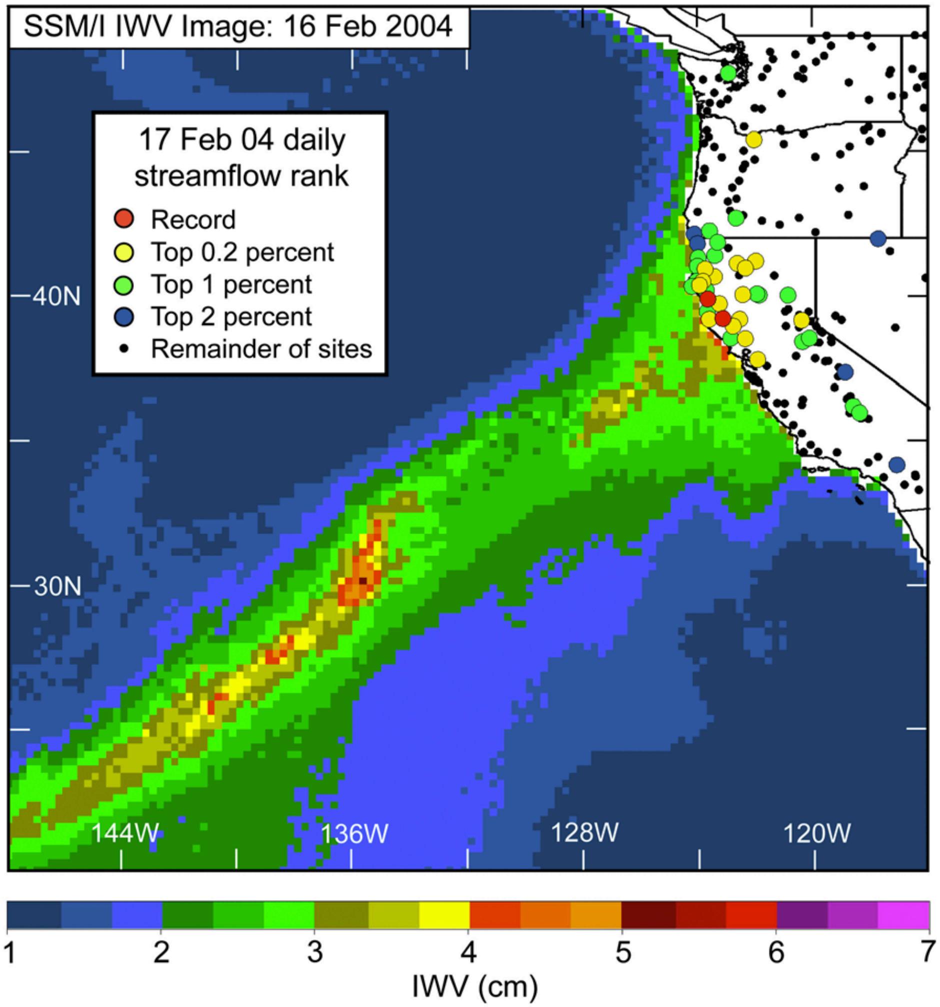
	QPE	Day 1	Day 2	Day 3
>3"	62	42	40	23
>5"	16	2	2	0

Precipitation (in/24 hour)

Only 2 of 16 events >5”/24 hr were even predicted!

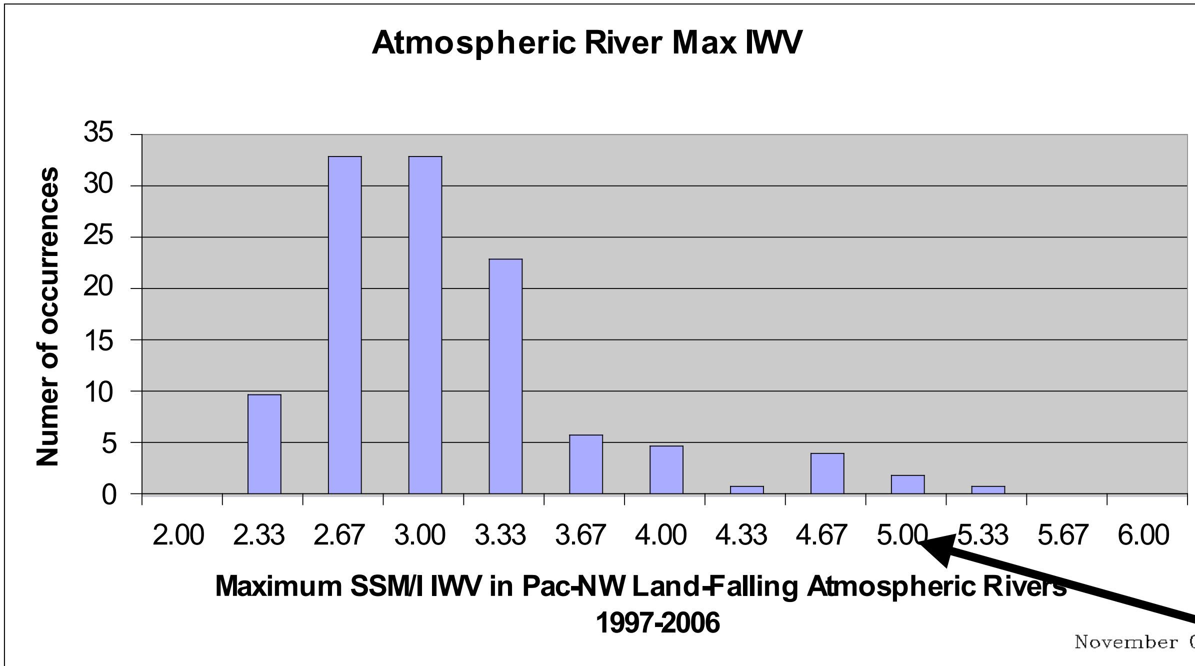

Information
Users
Decisions
Results
HYDROLOGY
Highly Accurate River Forecast Flow
*Public and private water suppliers
*Energy Producers
*Recreation
*Natural Resources
*Flood Management
*When and how much water to release
*Evacuation orders
*Sandbagging
*Flood mitigation strategies
*Safety
*Efficiency
*Environment
*Mobility
*Economic Vitality
MEASURING THE VALUE
System Performance (Output)
User Acceptance (Output)
Decision Effectiveness (Output)
Operational Improvements (Output)

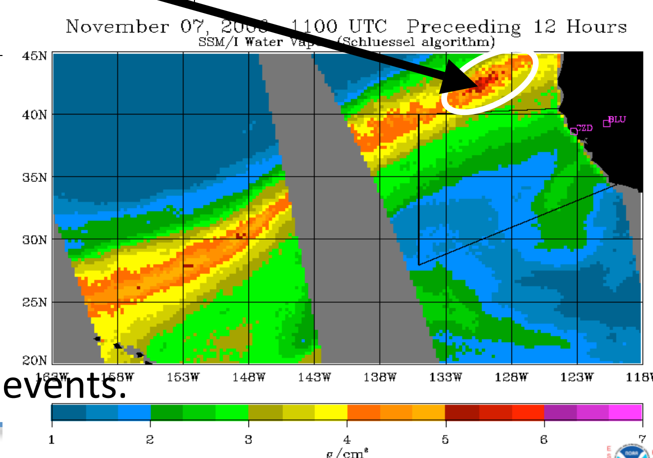
The Culprit: Atmospheric Rivers



Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, C. R. Cayan, and A. B. White 2006: Flooding on California's Russian River: The Role of Atmospheric Rivers. *Geophys. Res. Lett.*, **33**, L13801

Atmoshperic Rivers: A Key Mechanism for Extreme Precipitation on the West Coast



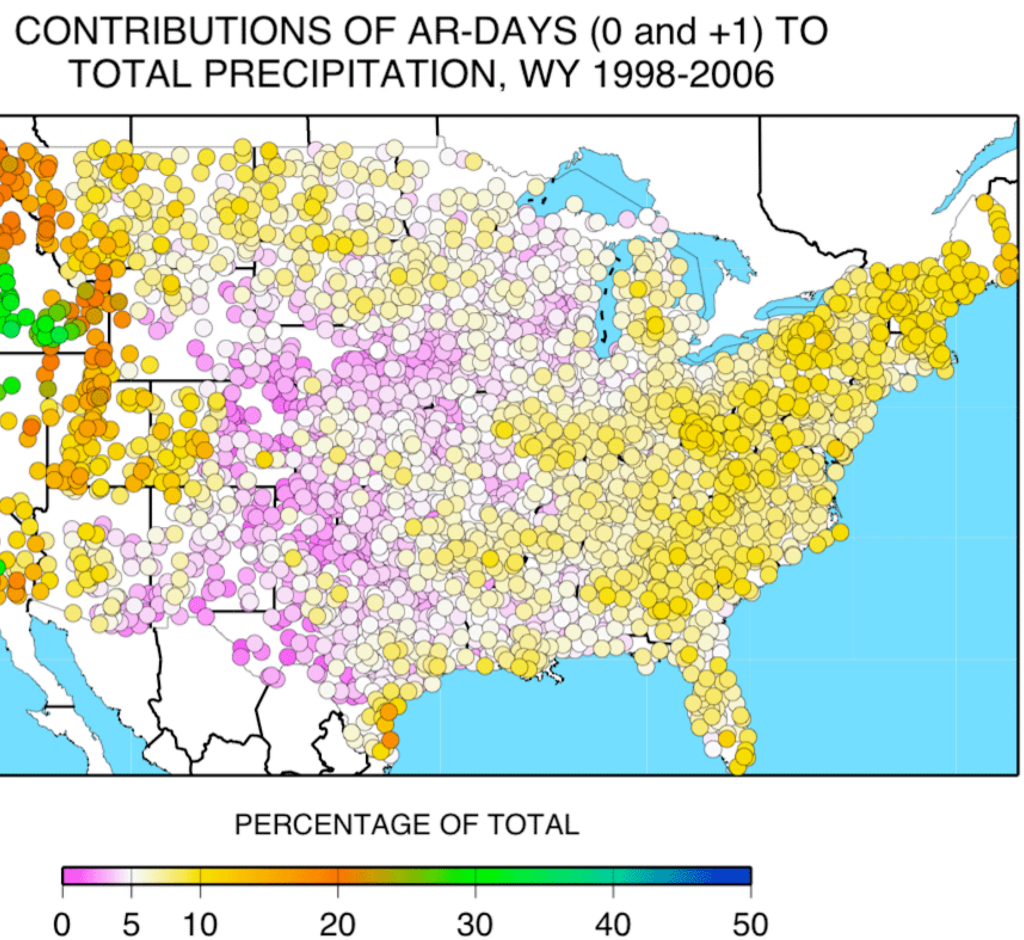


Conclusion:

The Fall 2006 event in the Pac-NW was associated with a landfalling atmospheric river. This is similar to the Ralph et al. (2006, GRL) result for the Russian River floods from 1997-2006.

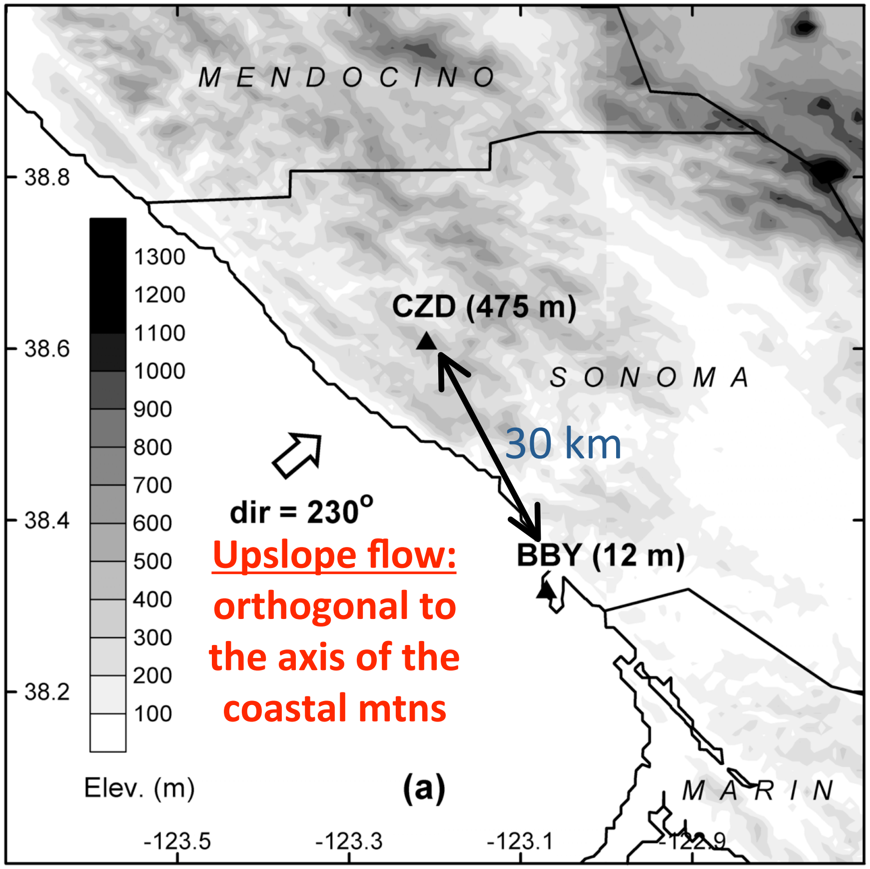
The event was tied for 2nd in terms of maximum IWV out of 118 events.

South Coast AR Landfalls:



Percentage of the total precipitation attributable to ARs for water years 1998-2006, based on the inventory of landfalling AR days in California determined from SSM/I satellite imagery (courtesy of Mike Dettinger, Scripps).

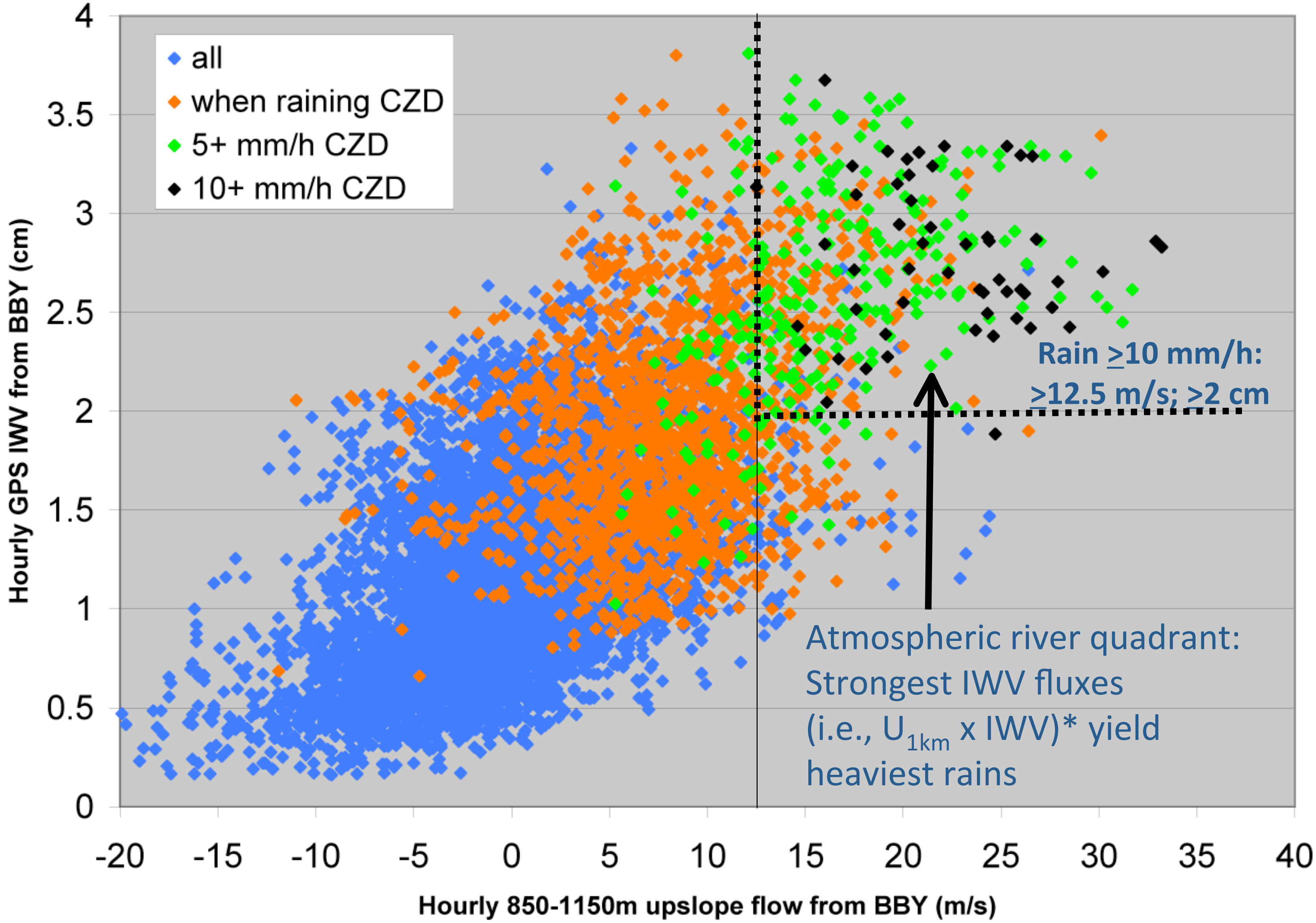
Developed real-time monitoring of vapor transports to assess the orographic forcing, based on published research using wind profilers, as well as GPS receivers that measure IWV



Neiman et al. (2002), *MWR*

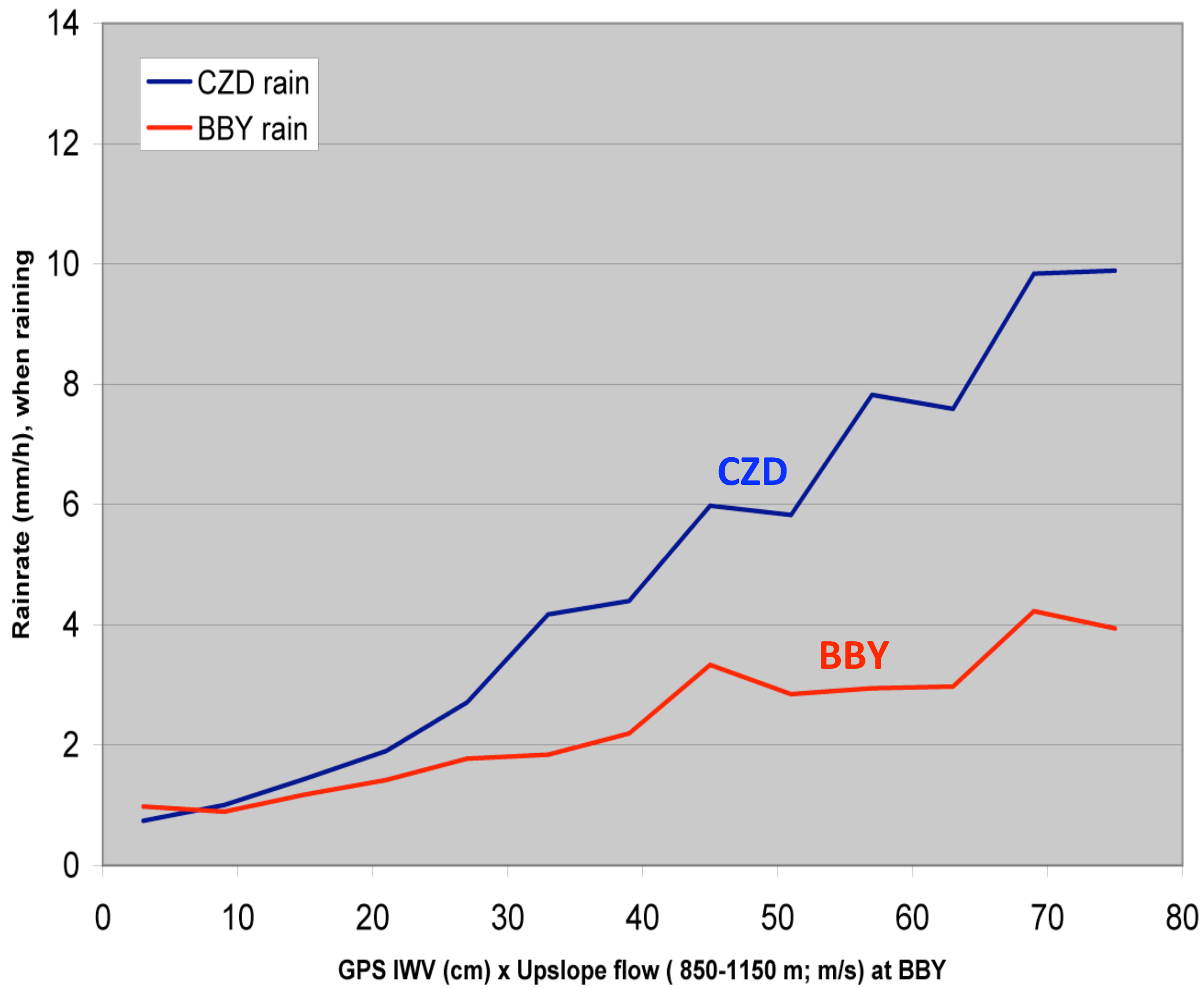
- Flood-prone Russian River Basin northwest of San Francisco: 2000/01, 2003/04, 2004/05, 2005/06
- Analyses for when the following observing systems were simultaneously operating – (a) Bodega Bay (BBY): GPS-IWV unit, 915-MHz wind profiler, rain gauge (b) Cazadero (CZD): rain gauge
- Total rainfall: CZD = 4217 mm, BBY = 2016 mm
- 9548 **hourly** data points

Neiman et al. (2008), *Water Management*



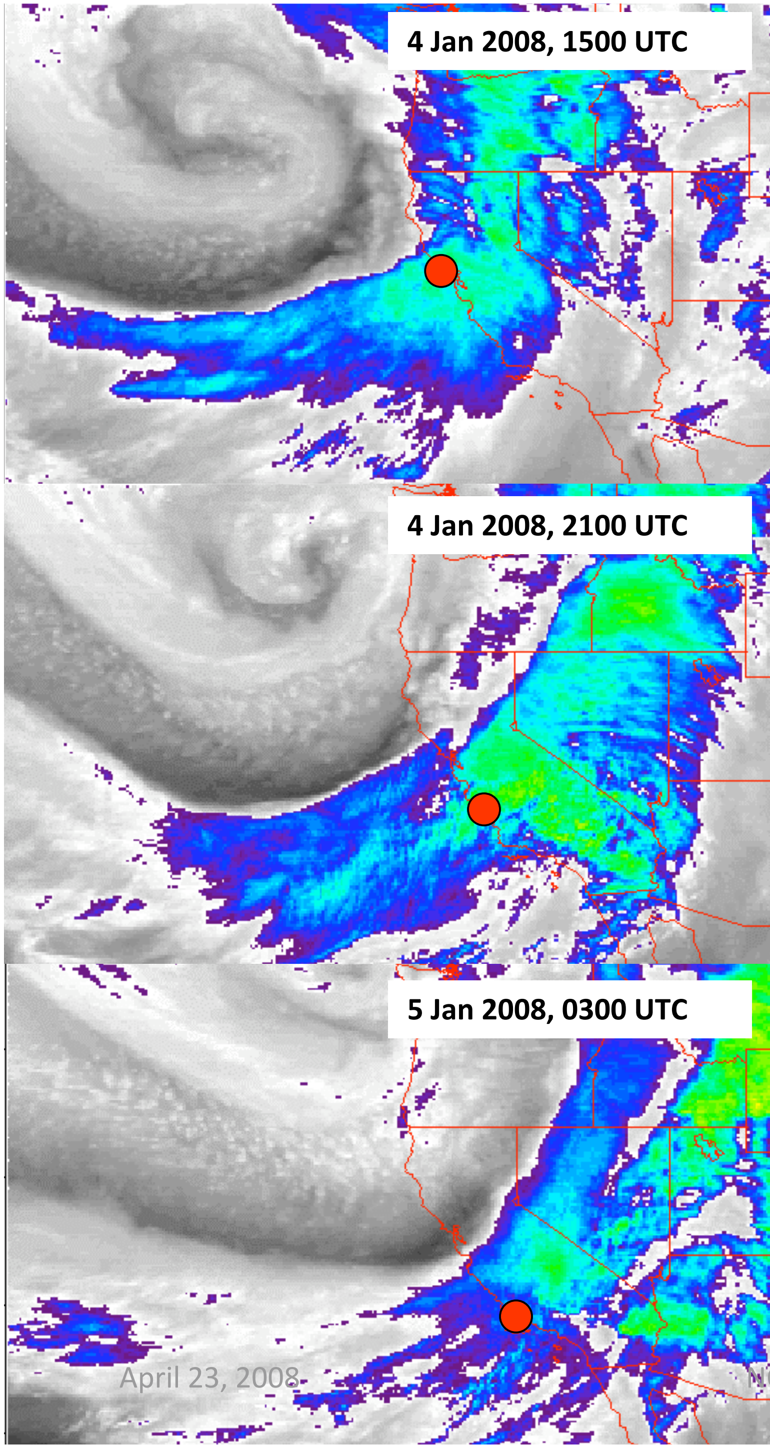
*Nearly 2/3 of tropospheric water vapor is in the lowest 2 km MSL.
Hence, to first order, the IWV flux provides a close estimate
of the low-level water-vapor transport into the coastal mountains.

Bulk Upslope IWV Flux vs. Rainrate

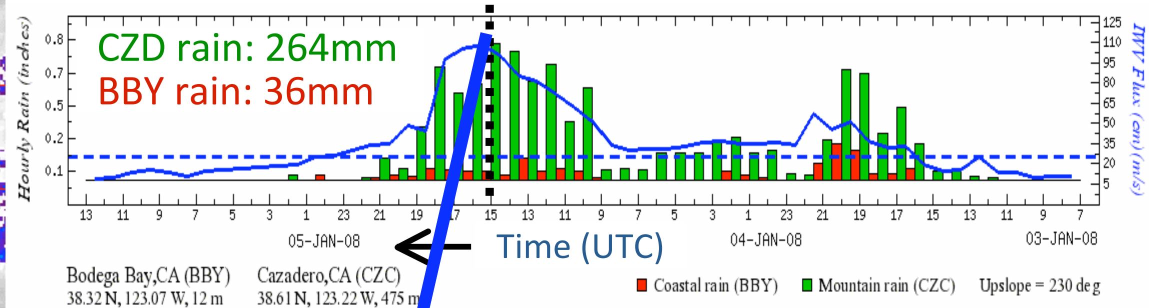


Rainrate and orographic rain enhancement at CZD increases with increasing bulk upslope IWV flux,

i.e., with strengthening AR conditions

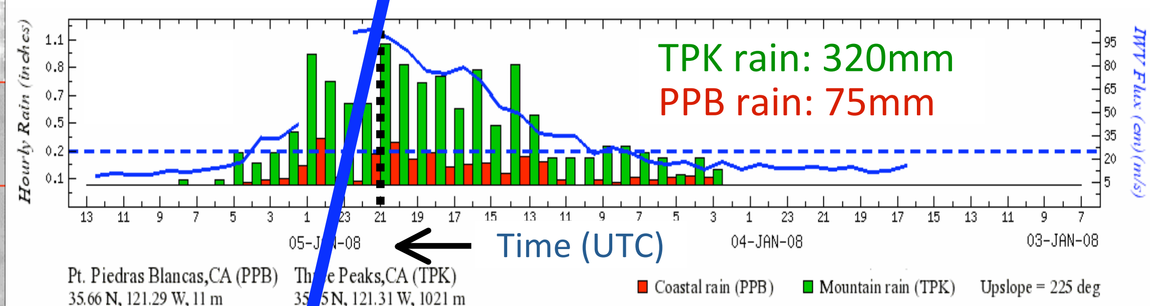


Time of max. IWV flux at BBY: 1500 UTC 4-Jan-08



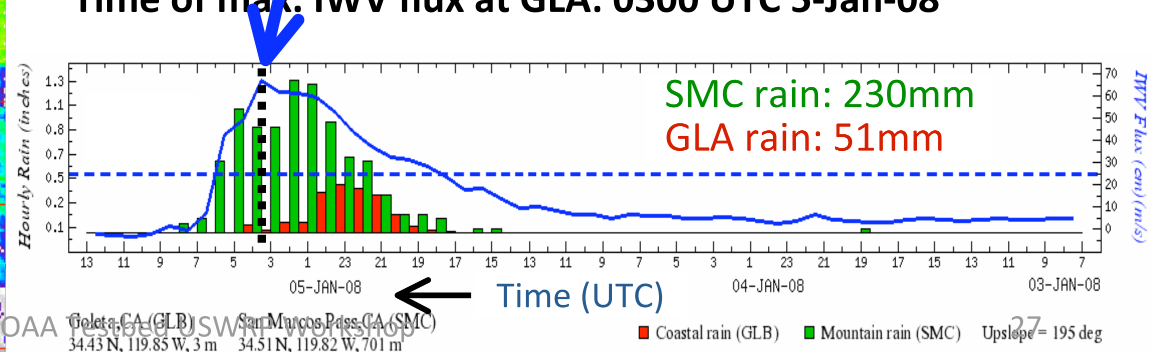
Max. IWV flux in AR highly correlated with max. mountain rainfall at each site

Time of max. IWV flux at PPB: 2100 UTC 4-Jan-08



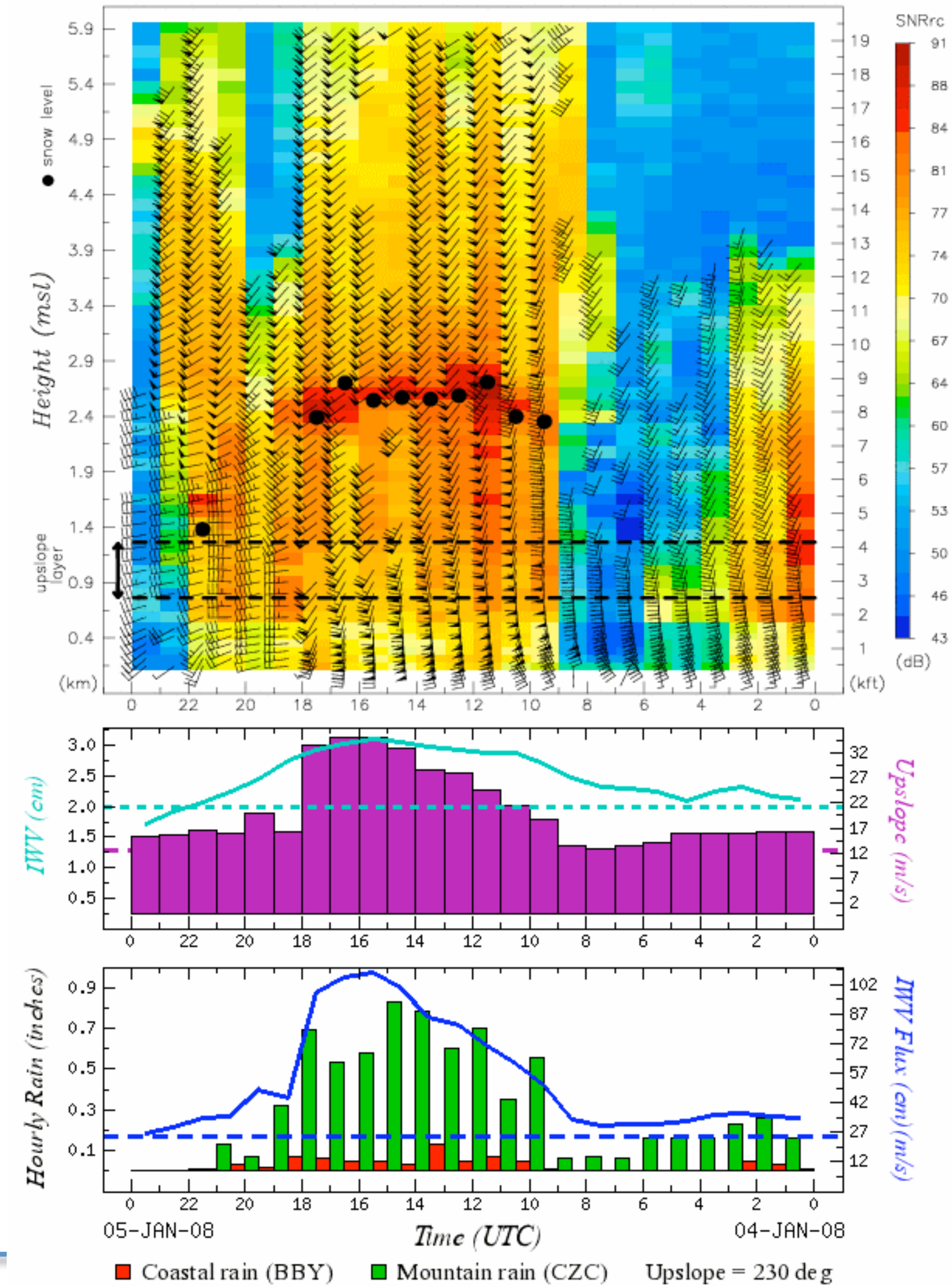
AR Propagation: ~12 m s^{-1}.
½-day lead time for SoCal

Time of max. IWV flux at GLA: 0300 UTC 5-Jan-08

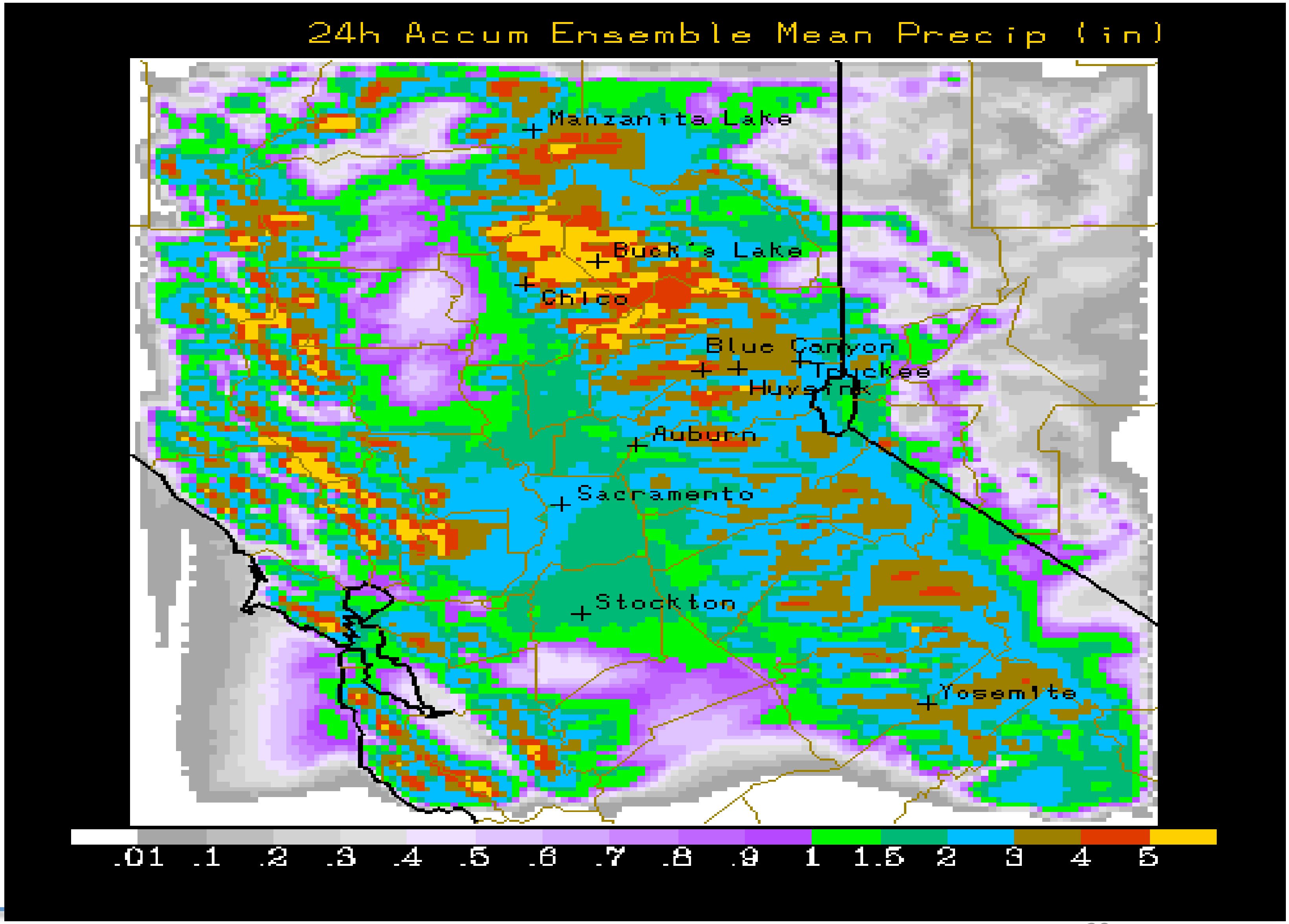


1st generation IWV flux tool: Observations only

-Coastal wind profiler
-Coastal GPS receiver
-Coastal/mtn rain gauges



Ensemble Mean Precipitation Forecast 4-5 Jan 2008 00GMT (24 hr forecast ending 5/00GMT): Most intense period



2nd generation flux tool: Observations & model

ARW Model: NOAA/GSD:

-5 km resolution; 51 levels

-LAPS initial conditions

-GFS for lateral BCs (NAM)

-Schultz microphysics

-model reinitialized hourly

-generates 12-h forecast

-available 0.9-1.8 h later

Model tendencies:

-no gap flow; too much flux/QPF

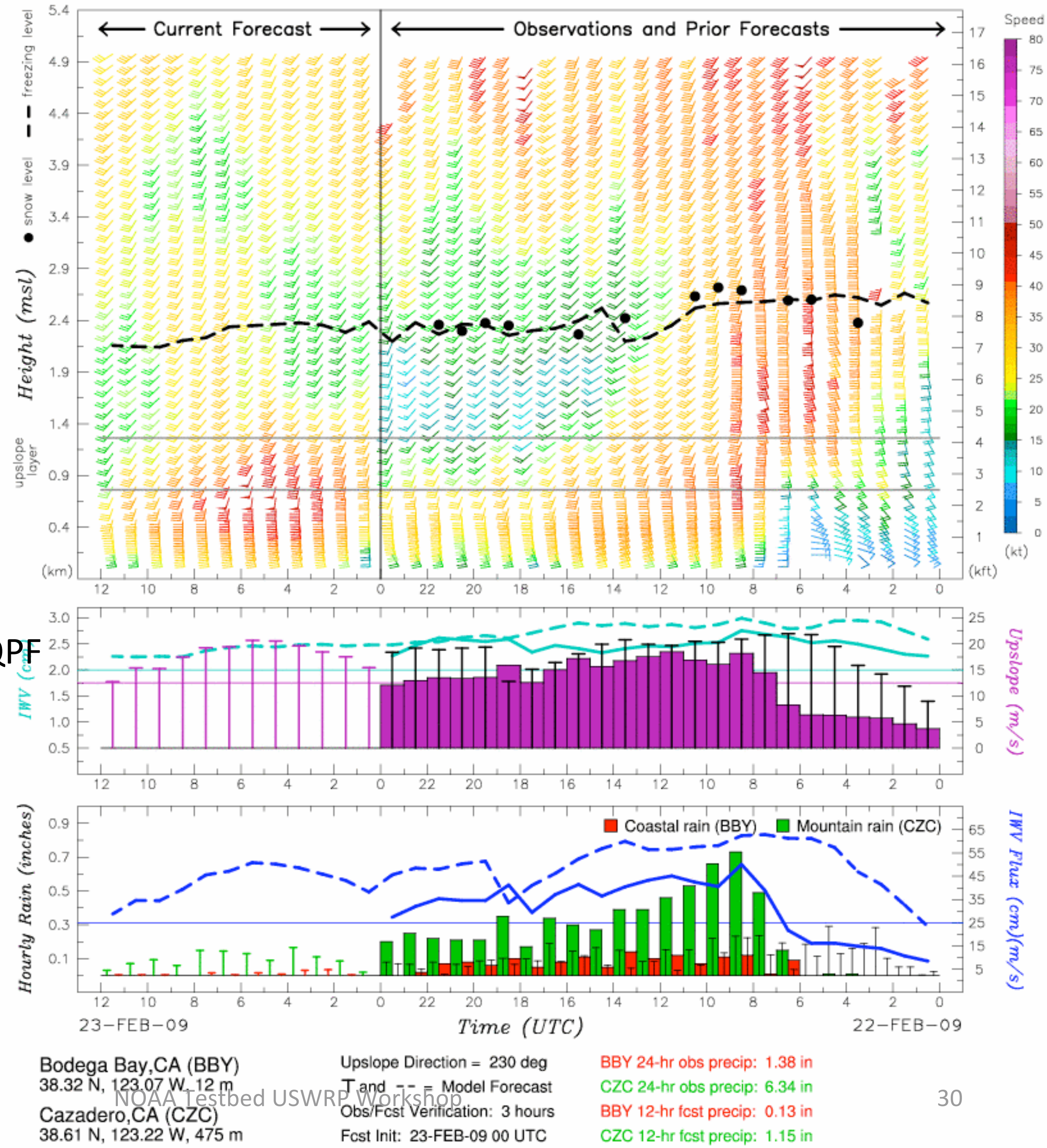
-overestimate upslope flow

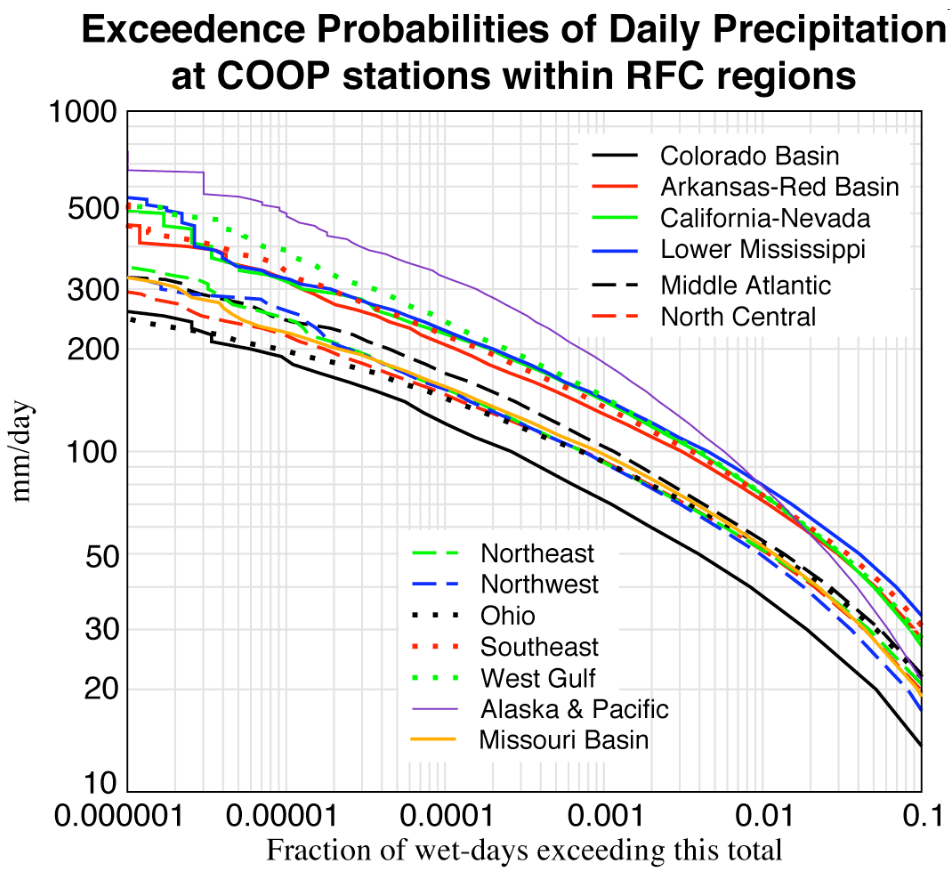
-closer on IWV

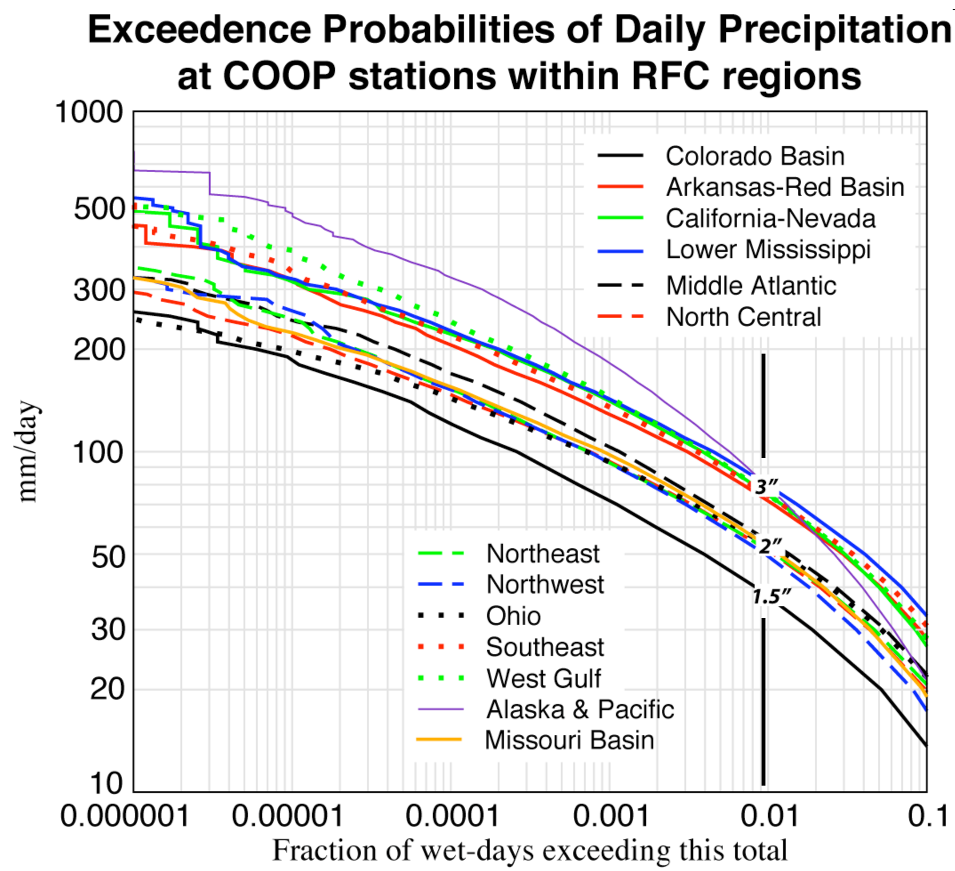
-overestimate IWV flux

-way underestimate mtn QPF

Comparison of obs and model serves to calibrate predicted orographic forcing and resulting QPF in the short range.




Exceedence Probabilities of Daily Precipitation
at COOP stations within RFC regions
1000
500
300
200
100
50
30
20
10
mm/day
0.000001
0.00001
0.0001
0.001
0.01
0.1
Fraction of wet-days exceeding this total
Colorado Basin
Arkansas-Red Basin
California-Nevada
Lower Mississippi
Middle Atlantic
North Central
Northeast
Northwest
Ohio
Southeast
West Gulf
Alaska & Pacific
Missouri Basin


Exceedence Probabilities of Daily Precipitation
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1000
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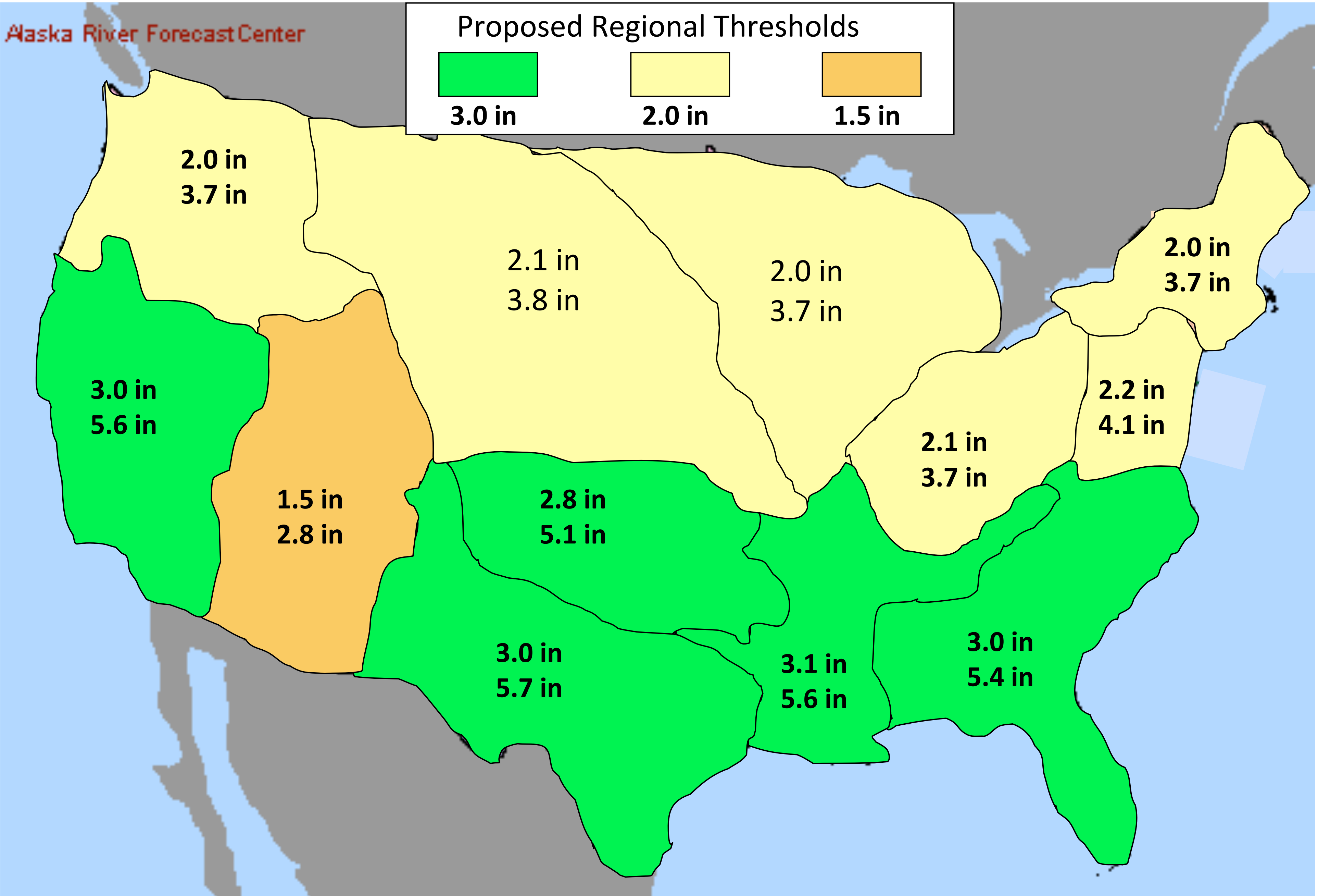
0.000001
0.00001
0.0001
0.001
0.01
0.1
Fraction of wet-days exceeding this total
Colorado Basin
Arkansas-Red Basin
California-Nevada
Lower Mississippi
Middle Atlantic
North Central
Northeast
Northwest
Ohio
Southeast
West Gulf
Alaska & Pacific
Missouri Basin
3″
2″
1.5″


Alaska River Forecast Center
Proposed Regional Thresholds
3.0 in
2.0 in
1.5 in
2.0 in
3.7 in
2.1 in
3.8 in
2.0 in
3.7 in
2.0 in
3.7 in
3.0 in
5.6 in
2.2 in
4.1 in
2.1 in
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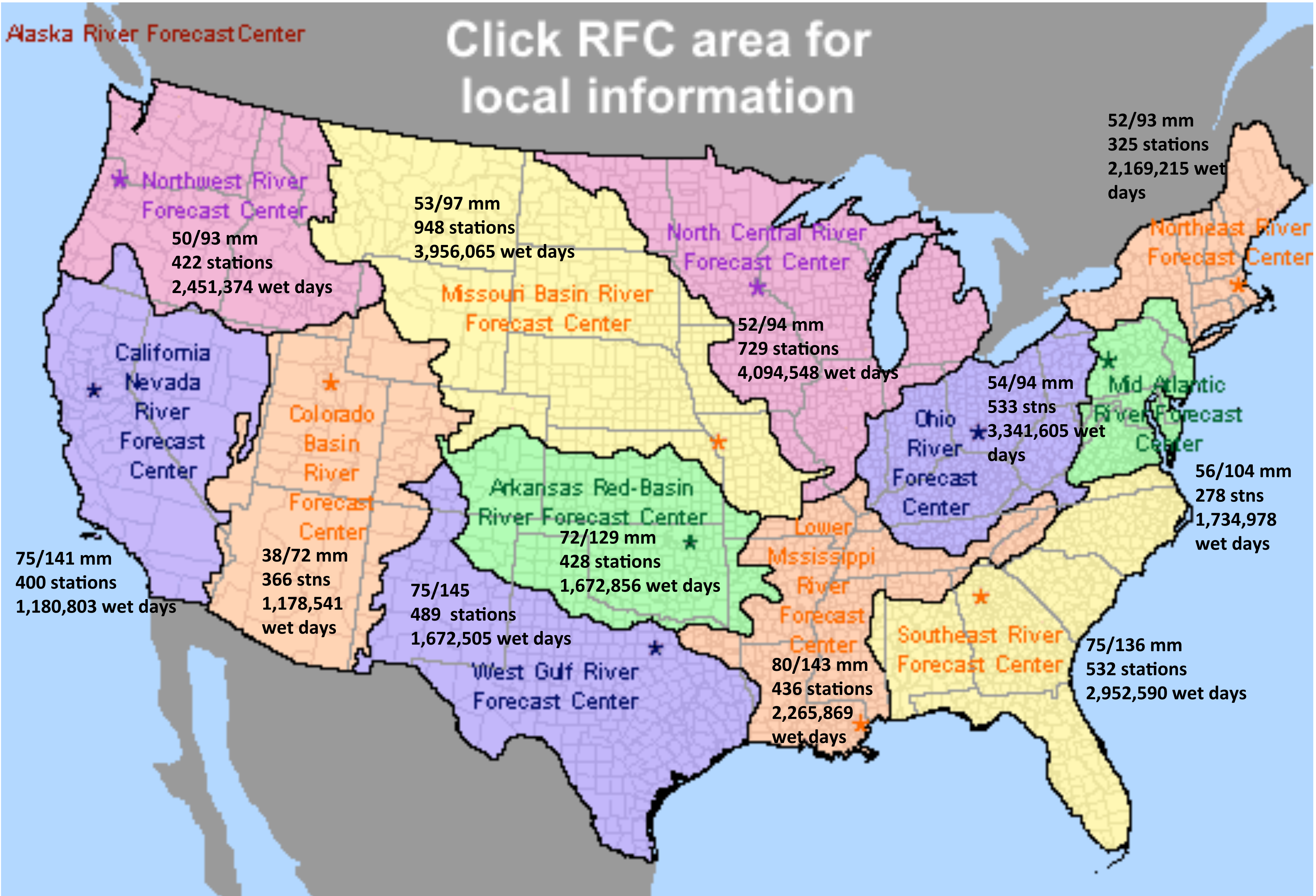
5.6 in
3.0 in
5.4 in


Alaska River Forecast Center
Click RFC area for local information
Northwest River Forecast Center
50/93 mm
422 stations
2,451,374 wet days
53/97 mm
948 stations
3,956,065 wet days
Missouri Basin River Forecast Center
North Central River Forecast Center
52/94 mm
729 stations
4,094,548 wet days
52/93 mm
325 stations
2,169,215 wet days
Northeast River Forecast Center
California Nevada River Forecast Center
Colorado Basin River Forecast Center
Mid Atlantic River Forecast Center
54/94 mm
533 stns
3,341,605 wet days
Ohio River Forecast Center
56/104 mm
278 stns
1,734,978 wet days
Arkansas Red-Basin River Forecast Center
72/129 mm
428 stations
1,672,856 wet days
75/141 mm
400 stations
1,180,803 wet days
38/72 mm
366 stns
1,178,541 wet days
75/145
489 stations
1,672,505 wet days
Lower Mississippi River Forecast Center
Southeast River Forecast Center
75/136 mm
532 stations
2,952,590 wet days
West Gulf River Forecast Center
80/143 mm
436 stations
2,265,869 wet days

Thank You, Questions?

http://hmt.noaa.gov/

Backup Slides

Requirements

- 10/2008: Lautenbacher's Farewell – "The ability to provide clean, safe and available water - the single largest challenge for a world with expanding population and a changing climate - must play a unifying role within the NOAA organization and have the highest priority for NOAA's leadership goals…"
- 11/2008: NOAA's Transition Briefing included the strategic priority "to improve drought and flood forecasts by integrating water information services"

NRC Report

The NRC report "NOAA's Role in Space-Based Global Precipitation Estimation and Application" recommends the NOAA HMT:

"There will be a symbiotic relationship between GPM and the Hydrometeorological Testbed. The Hydrometeorological Testbed will use GPM data as an additional input for experimentation and demonstration, and GPM will obtain validation elements from the Hydrometeorological Testbed."

From the AMS Policy Statement on Water Resources in the 21st Century

"The provision of adequate freshwater resources for humans and ecosystems will be one of the most critical and potentially contentious issues facing society and governments at all levels during the 21st century.

NOAA

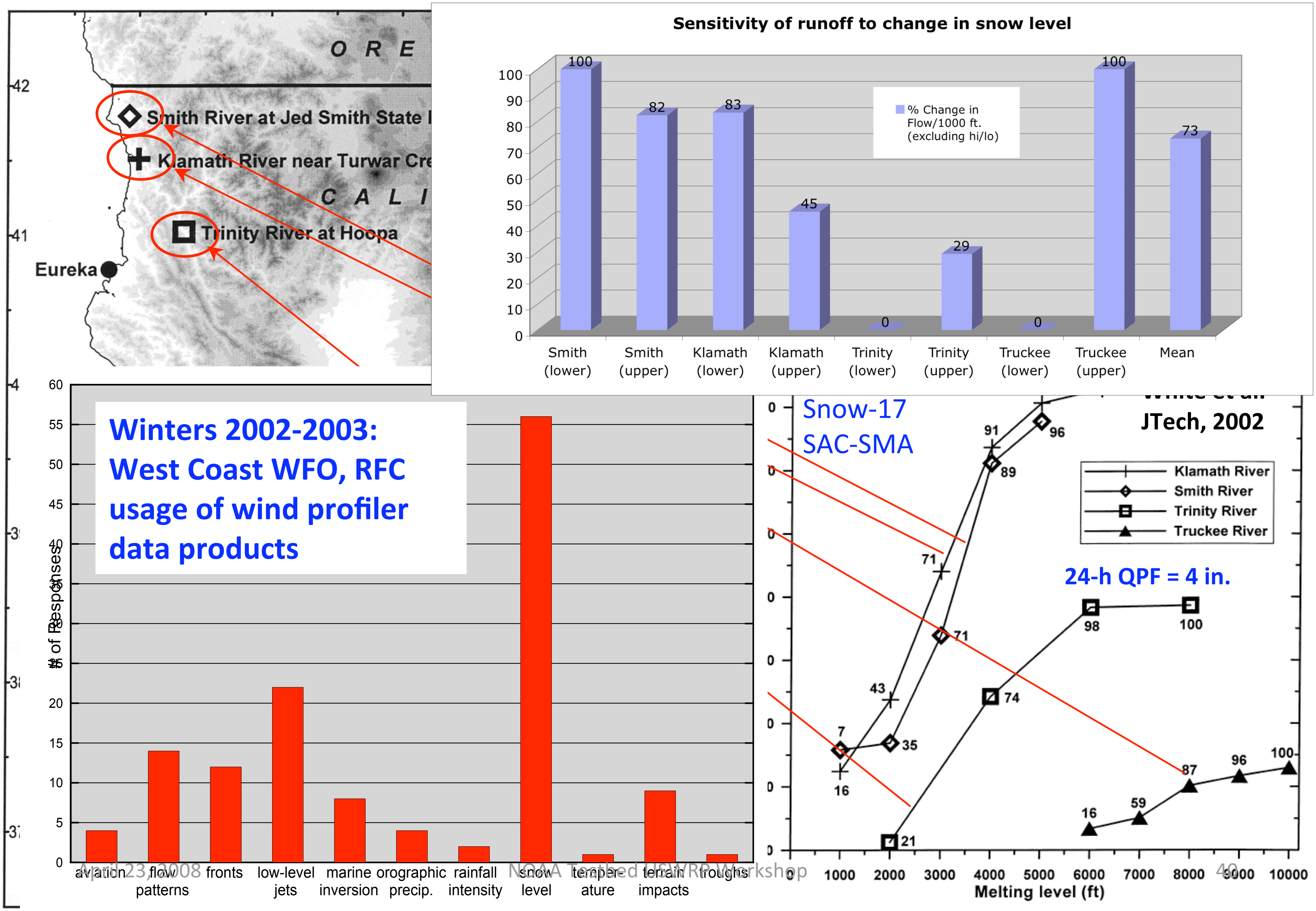
NOAA VISION

An informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions

NOAA MISSION

To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs

Sensitivity of Runoff to Change in Snow Level



Initial Transition Projects Identified at R2O Workshop, Part 1

- High-resolution, ensemble QPFs
  – calibrate, validate
  – Ensemble means at 66 RFC forecast points
  – Gridded fields (including probabilistic info)
- Moisture Tools
  – GPSMet grids
  – Moisture flux verification tool

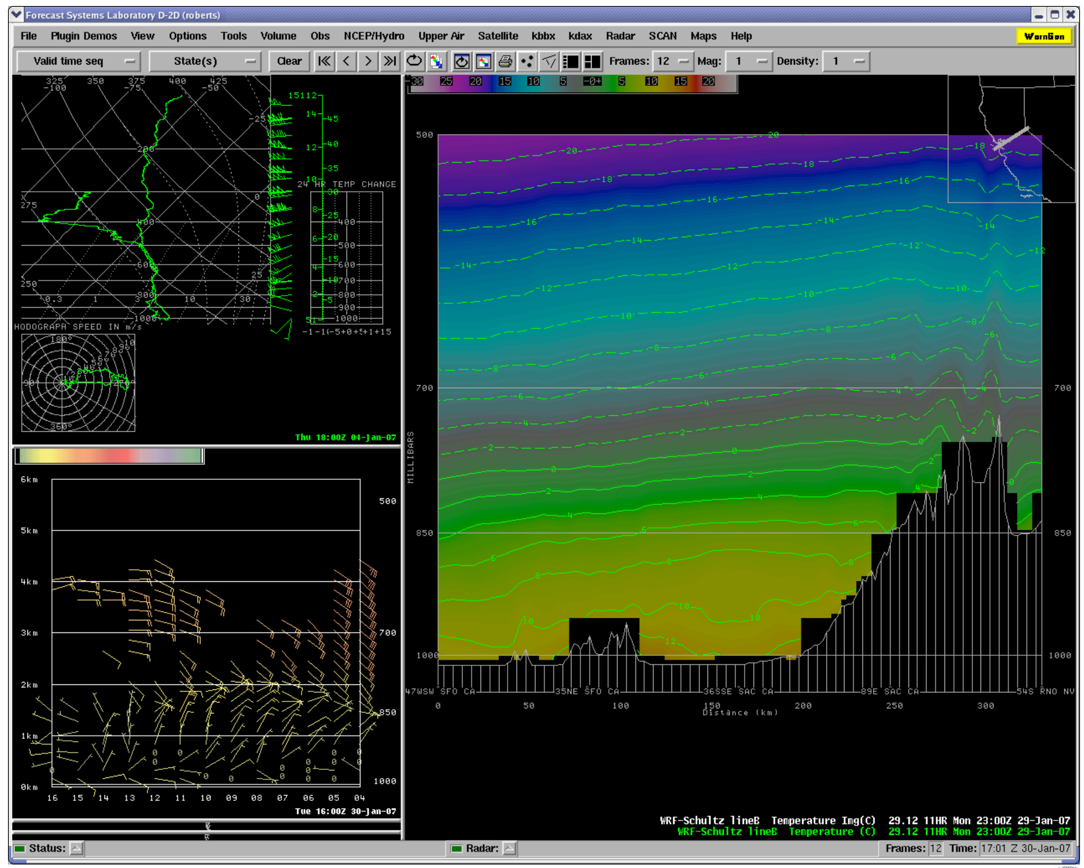
Initial Transition Projects Identified at R2O Workshop, Part 2

- Snow Information Tools
  - Gridded snow level from NMQ/Q2
  - point verification; model bias correction
- Atmospheric River Tools
  - Provide vapor flux anomaly tool; reforecasting product; atmospheric river intensity (observations-based)
  - Training needed
  - Working towards a unified product: PARTI = Pacific Atmospheric River Threat Indicator

Delivery to Field Offices & High Resolution, QPF Ensembles

- ALPS
  - Advanced Work Stations
  - Interface is like AWIPS
- MADIS
  - Ingests/assimilates data
  - Available in ALPS
  - Available in AWIPS
- World Wide Web

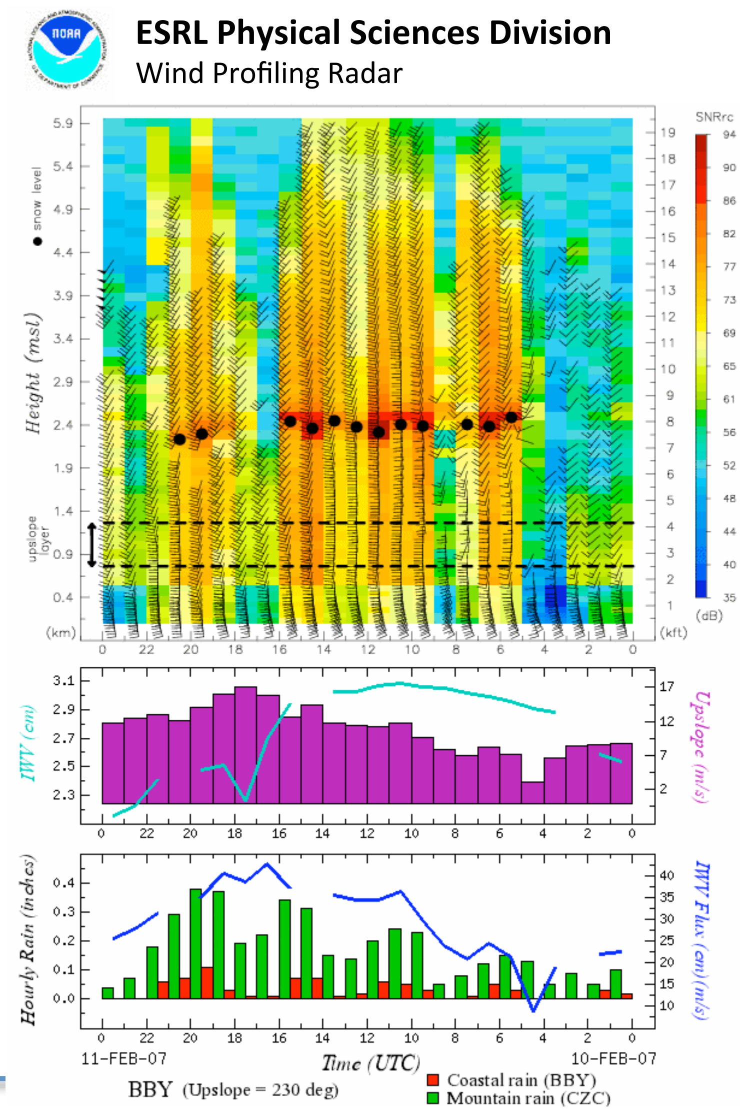
WRF cross section through the Sierras:

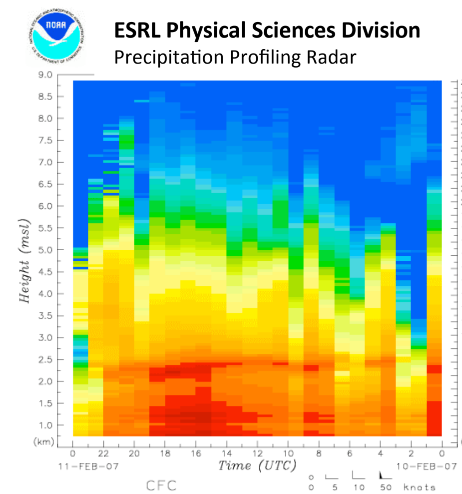


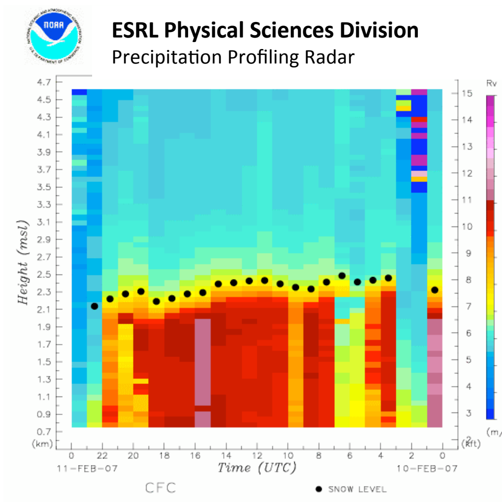
Real-time products

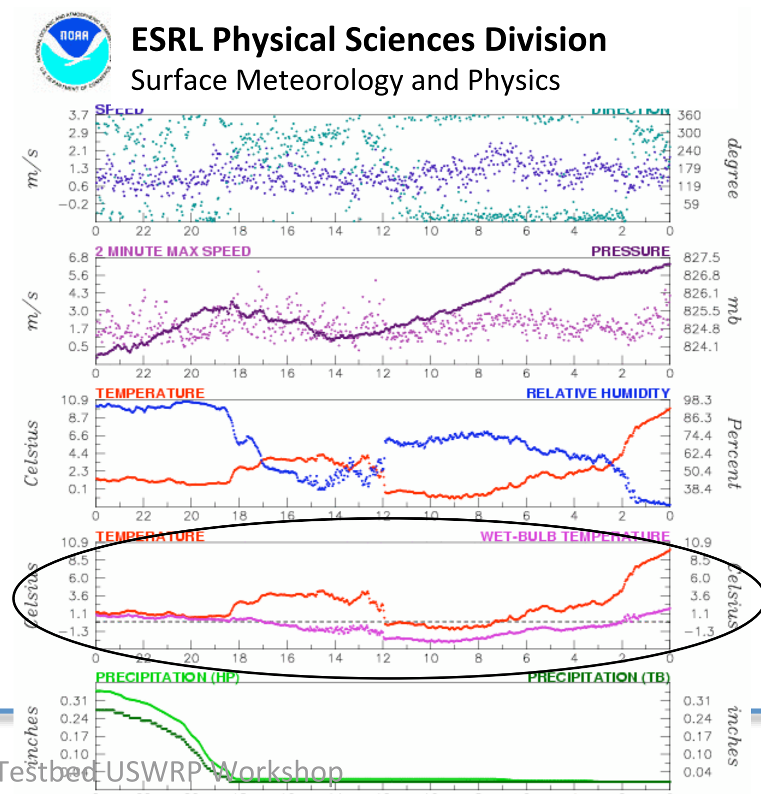
Snow Level

Integrated Water Vapor Flux





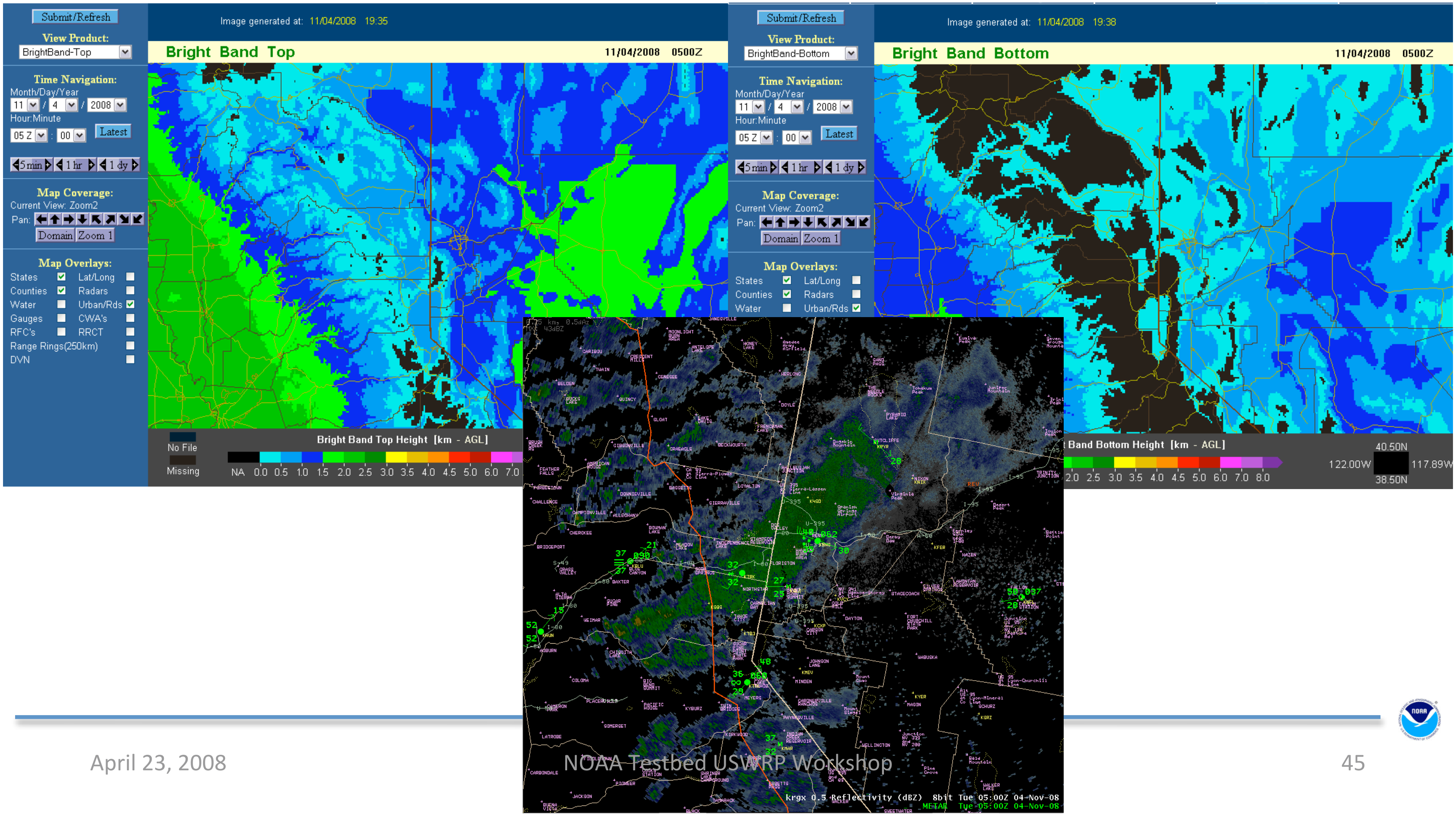




Wet-Bulb Temperature

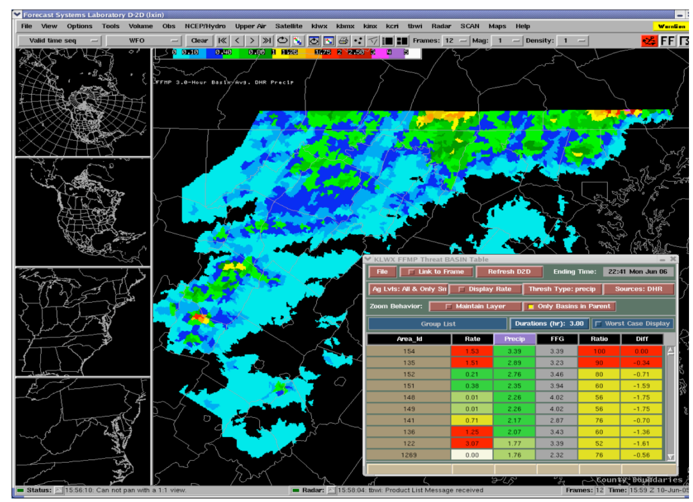
Bright Band Top & Bottom from NMQ/Q2

RUC 0C level modified by radar-derived bright band top/bottom



Next Steps

- Demonstration ongoing via HMT-West 2009/2010
  - Evaluation & verification
- Further integration of components ("PARTI")
- Enhanced Flood Response and Emergency Preparedness (2008-2013)
  - With CA DWR & Scripps
  - HMT Legacy: observations & modeling
- FFMP
  - Moisture flux guidance
  - Improved short-term QPF forecasts
  - Best multisensor QPE (bias adj.)
- HMT-SE
- AZ Soil Moisture w/CB-RFC



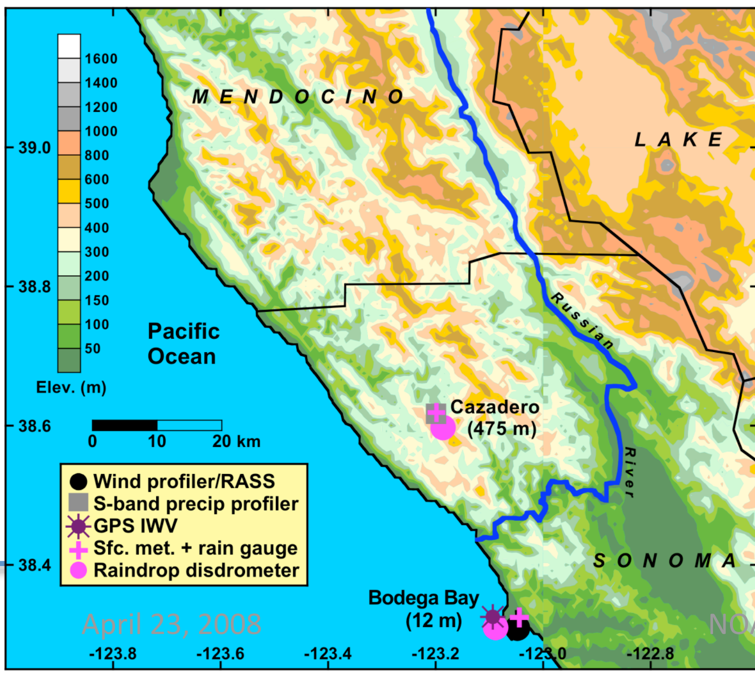
An Atmospheric River Observatory

Atmospheric River (AR) Observatory: Russian River Prototype

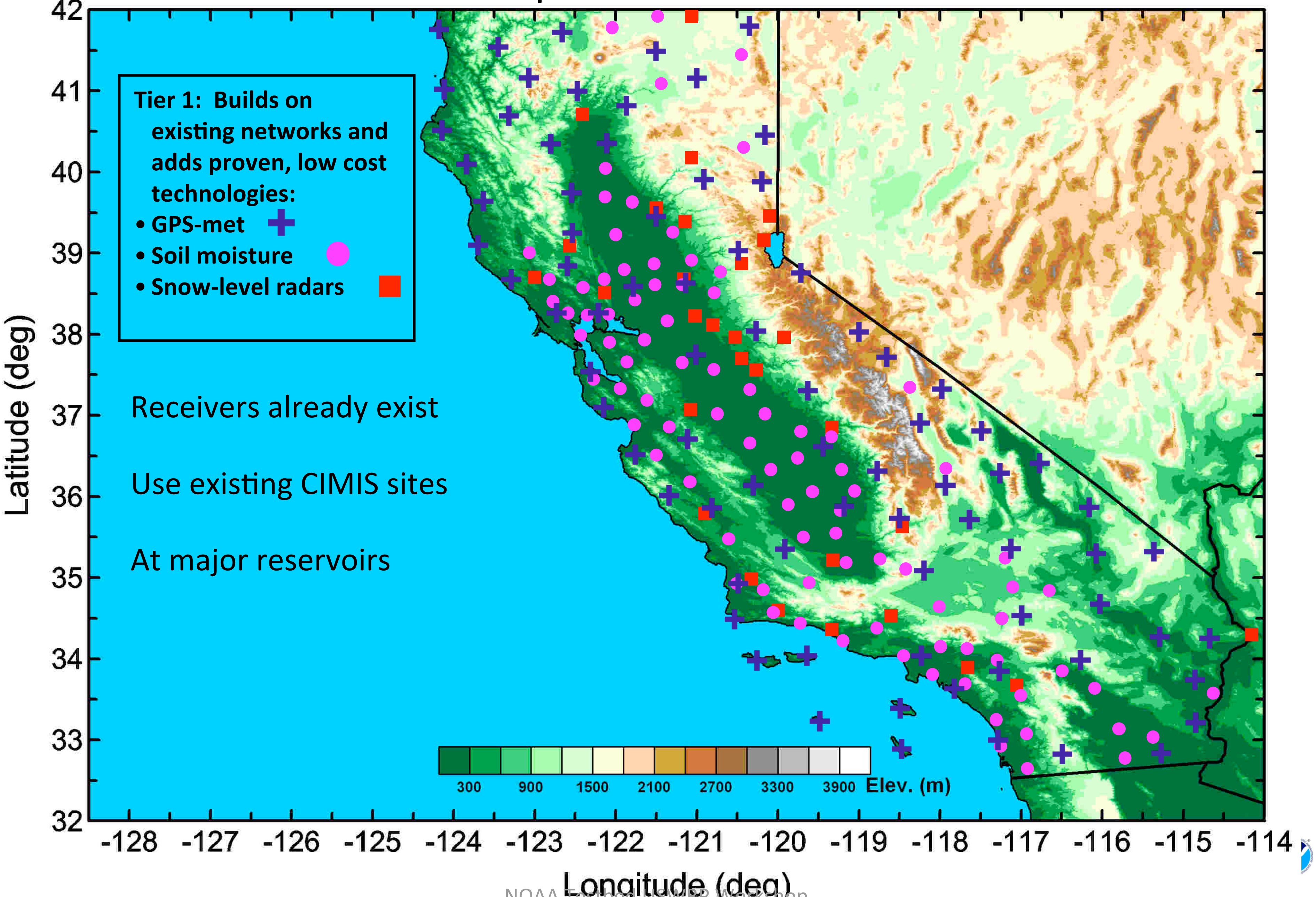
Objectives: Monitor key AR and precipitation characteristics.

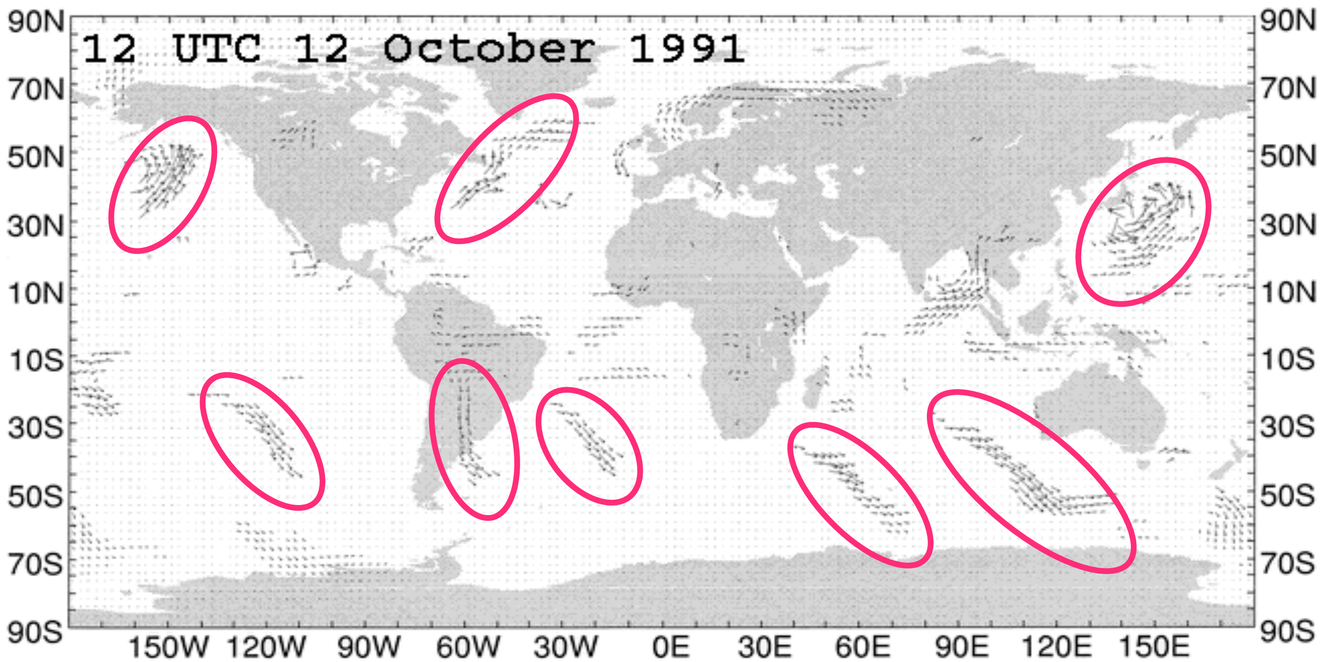
Observing systems:

1. Wind profiler/RASS
2. S-band radar
3. Disdrometer
4. Surface met
5. GPS-IWV
6. Rain gauges



Map of EFREP Tier I

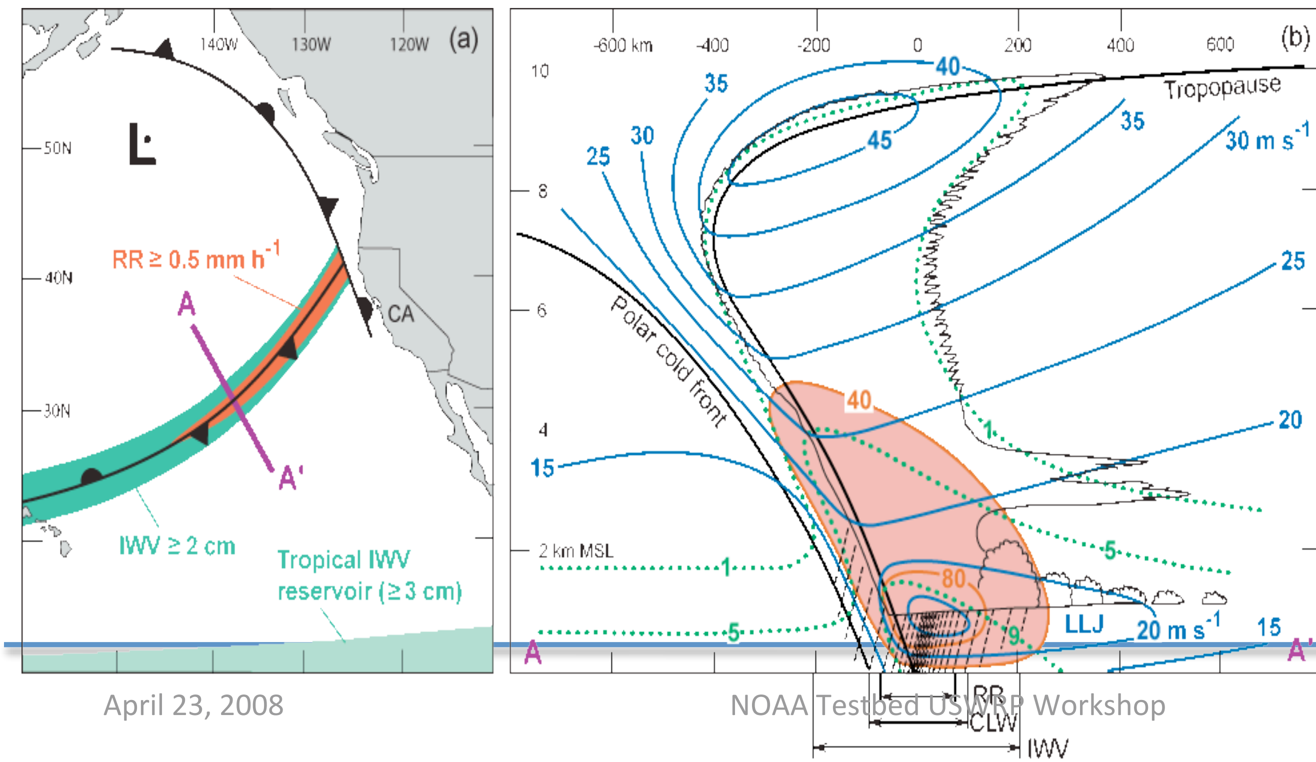




Zhu & Newell 1998

Model diagnostic study using the ECMWF

Atmos. rivers contain 95% of meridional water vapor flux at 35 latitude, but in <10% of the zonal circumference



Ralph et al. 2004

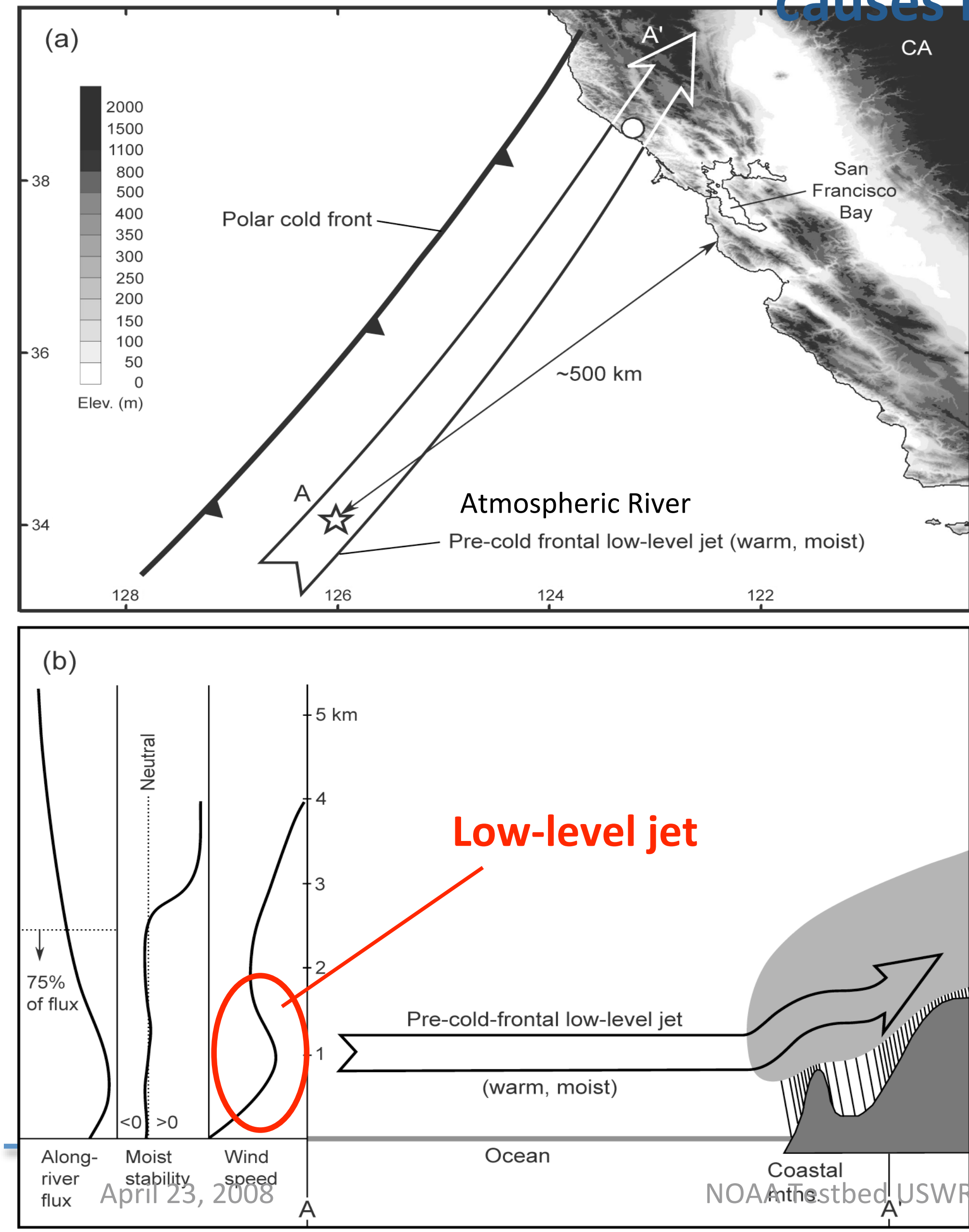
Observations confirm model study

-Lateral structure from satellite data (~400 km width per "river")

-vertical structure from case study

-Next step: statistically quantify vert. structure

When an Atmospheric River Strikes Coastal Mountains, it causes heavy rainfall



Ralph et al. (2005), *Mon. Wea. Rev.*

- 17 research aircraft missions offshore of CA documented atmospheric river structure.
- Wind, water vapor and static stability within atmospheric rivers are ideal for creation of heavy rainfall when they strike coastal mountains.
- These characteristics were present in both El Nino and Neutral winters

HMT R2O Workshop
May 20-21, 2008; Sacramento, CA
Attendees

OAR

1. T. Schneider - PSD
2. A. White - PSD
3. D. Kingsmill - PSD
4. P. Neiman - PSD
5. D. Gottas - PSD
6. C. Williams - PSD (notetaker)
7. P. Schultz - GSD (phone)
8. W. Roberts - GSD
9. K. Howard - NSSL

NWS

1. R. Hartman - RFC
2. E. Strem - RFC
3. A. Henkel - RFC
4. A. Haynes - RFC
5. Mike Ekern - RFC
6. D. Kozlowski - RFC
7. E. Morse - SAC
8. J. Juskie - SAC
9. M. Smith - OHD
10. J. Schaake - OHD
11. W. Junker - NCEP
12. Don Cline - NOHRSC

Product I:
High Resolution, Ensemble Modeling

- Develop QPF Verification Tool (1st step)
  - Reconfigure "HMT-WRF" for broader domain
  - Rerun for past three years and calibrate ensemble calculations (calibrate to CNRFC derived QPE)
  - Produce QPF from ensemble models
  - Leverages DWR-EFREP Tier I proposal
- Operational Ensemble Means from "WRF-HMT" and Reforecast Technique
  - Extract data at 66 RFC forecast sites to support RFC-QPF grids
  - Provide visualization of ensemble means and ensemble properties

Product II: Moisture Tools

- Generate Gridded Map of Atmospheric Moisture (water vapor) over land
  - From GPSMet Sensors
  - Grid to be defined… (HRAP? GFE?)
  - Leverages DWR-EFREP Tier I proposal
- Moisture Flux Verification Tool for Models
  - From atmospheric river observatory observations

Product III: Snow Level Information

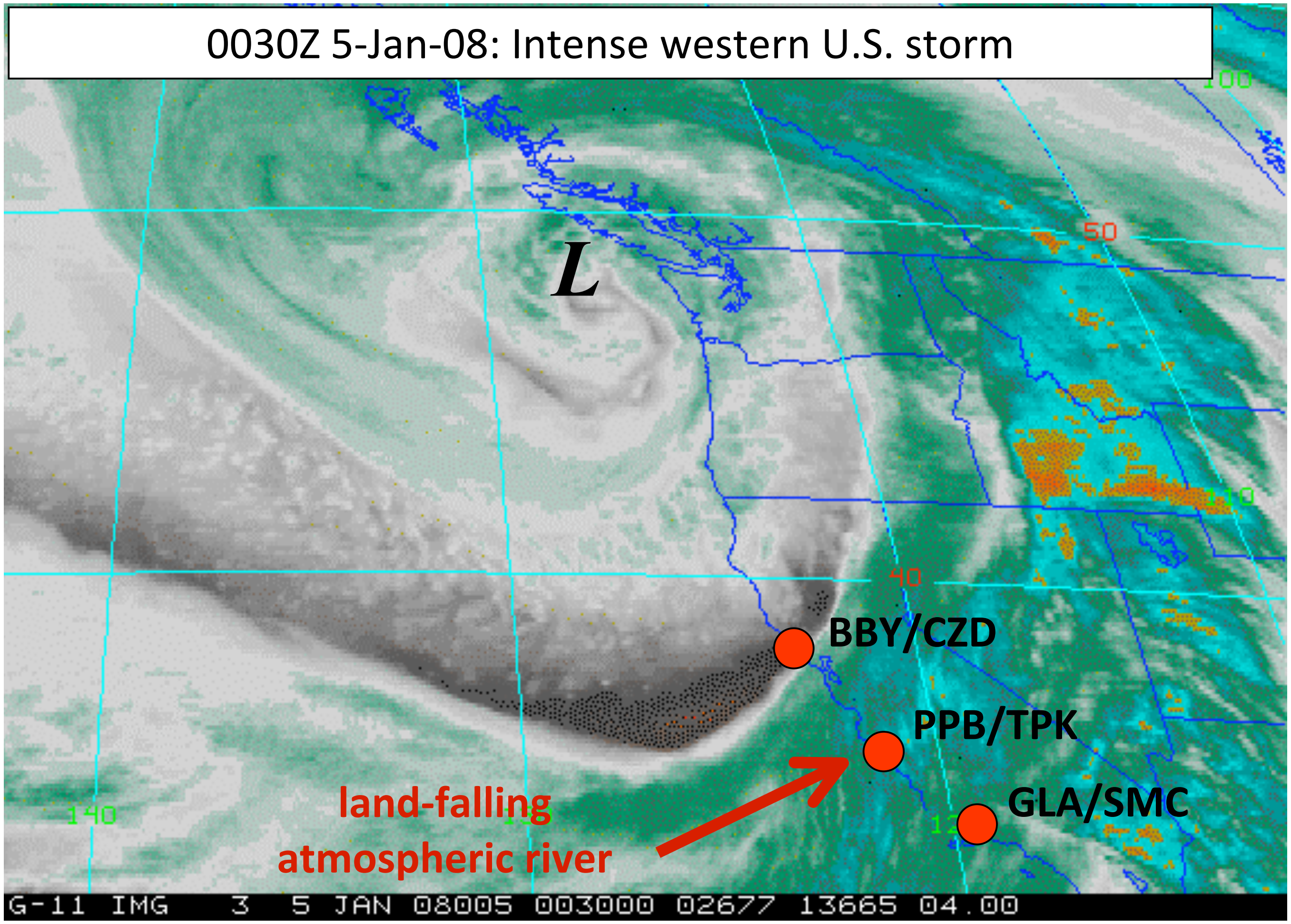
- Map of freezing level from Q2
  - Gridded file
  - Same domain as ALPS system for GFE
    - NSSL needs resolution, frequency, projection info (GFE Grids; RFC HRAP Grids)
- Feed snow level radar data into ALPS
  - From HMT and EFREP networks
  - (Long-term: merge these two products)
  - Radar/profiler obs
- !!! Basic model snow level verification tool
  - For GFS and “HMT-WRF” models
  - Bias-corrected GFS-based snow level (freezing level) forecasts to RFC (short term and long term)
  - Juskie/Nordquist: Q2 bias-corrected forecast field for baseline of model correction and “validation” in real-time. “Boise Verify Tool” to generate bias correction of GFS (short term)

Product IV: Atmospheric River Tools

- Diagnostic “heads-up” tool
  - Relate atmospheric river moisture content (obs + model) to historic floods
  - Goal is 7-day lead time; like an “Atmospheric River Early Warning System”
- Initially built on:
  - Junker moisture flux anomaly products (currently web-based)
  - Hamill and Whitaker Reforecast guidance
  - Satellite-derived atmospheric river intensity guidance (histograms)
  - These will be synthesized into a single index or indicator in future iterations

Goal: “Pacific Atmospheric River Threat Indicator (PARTI)”

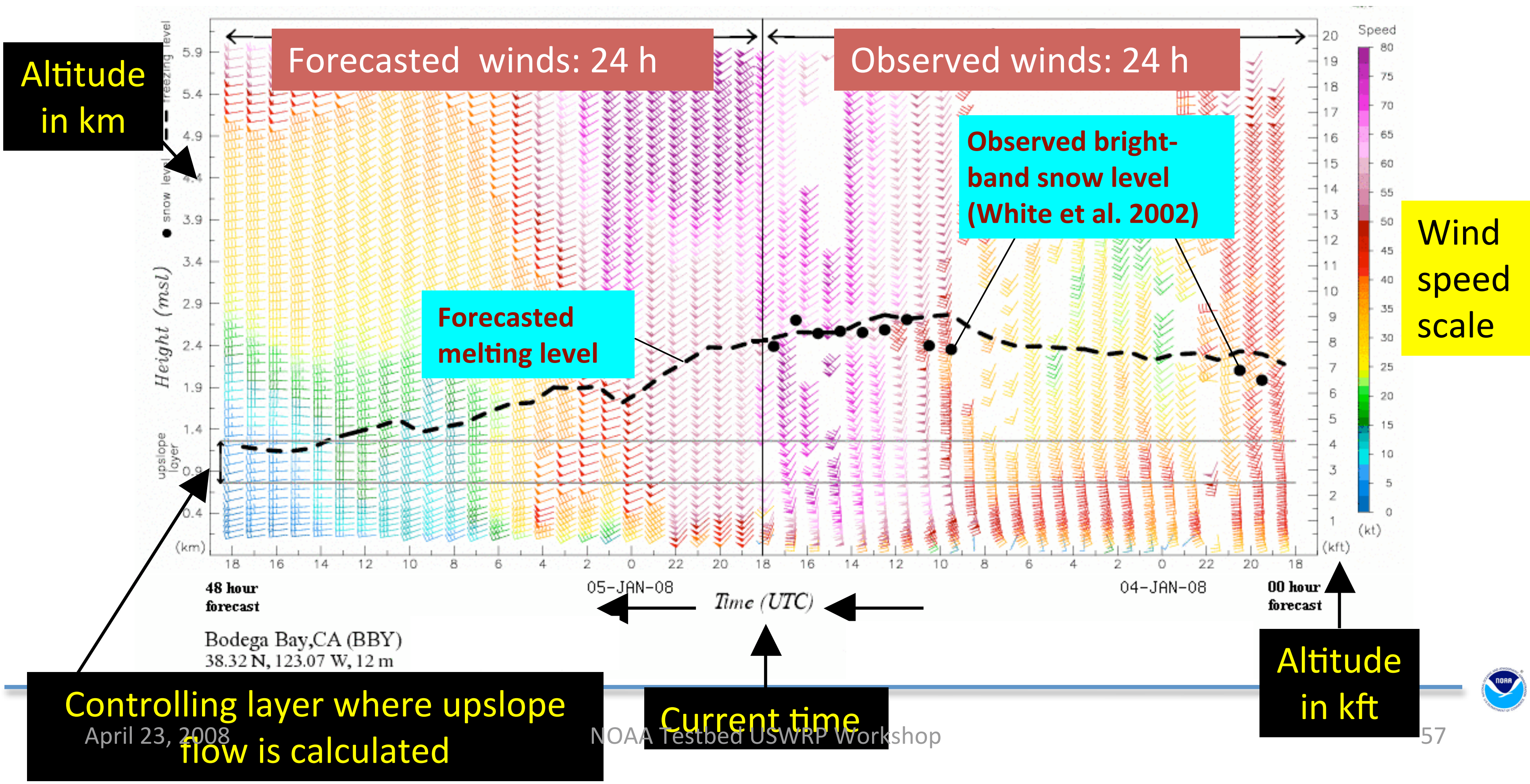
Prototype forecast tool tested at 3 couplets during NOAA's HMT-2008



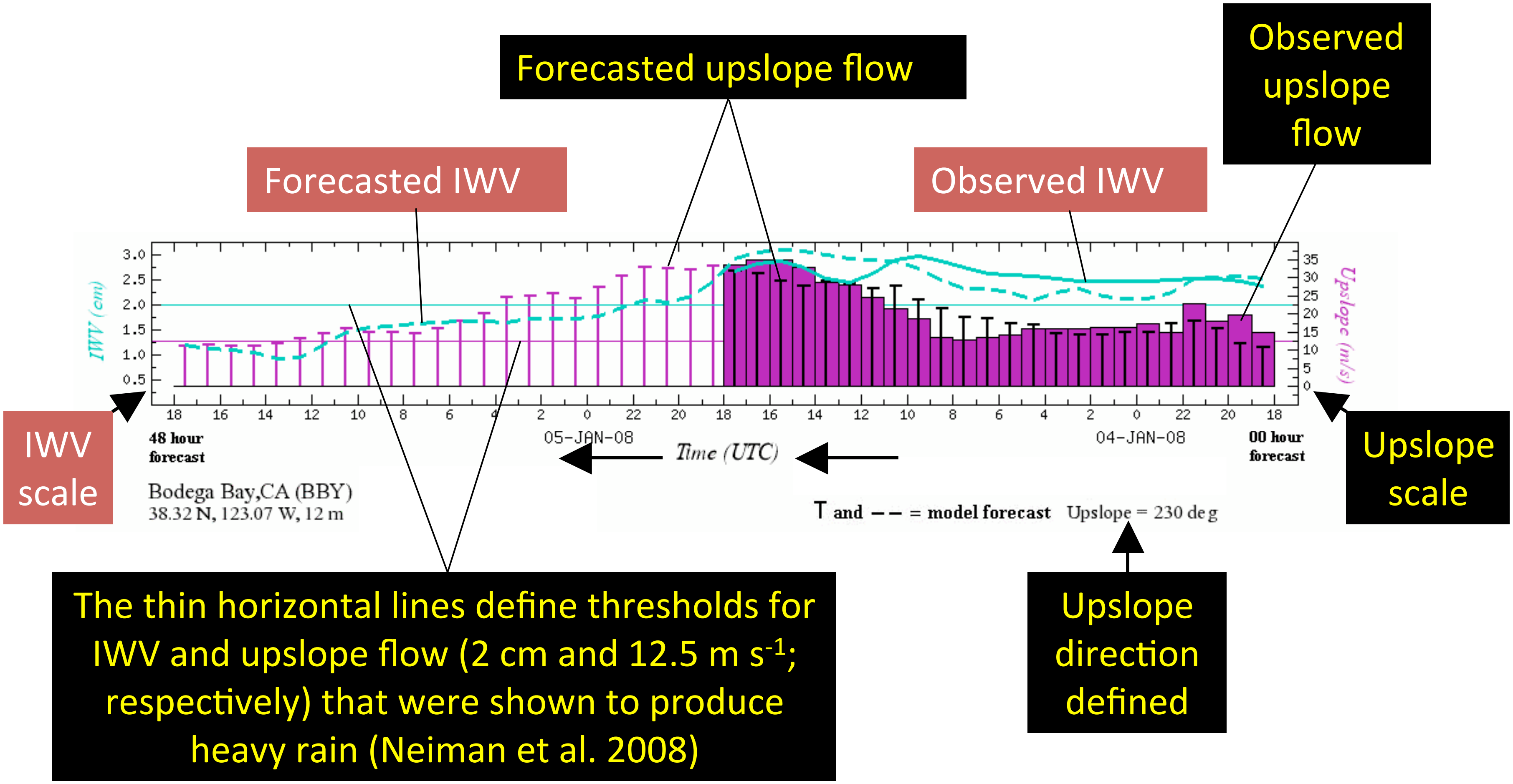
Couplet	**Coast** (*profiler, GPS, rain gauge*):	**Mountains** (*rain gauge*):
North:	Bodega Bay (BBY; 12 m MSL)	Cazadero (CZD; 475 m MSL)
Central:	Piedras Blancas (PPB; 11 m MSL)	Three Peaks (TPK; 1021 m MSL)
South:	Goleta (GLA; 3 m MSL)	San Marcos Pass (SMC; 701 m MSL)

The top of three panels of the forecast tool displays hourly wind profiles and snow levels

Model: Advanced Research WRF (ARW), 48-h duration
Grid configuration: 3 km horizontal, 30 vertical levels



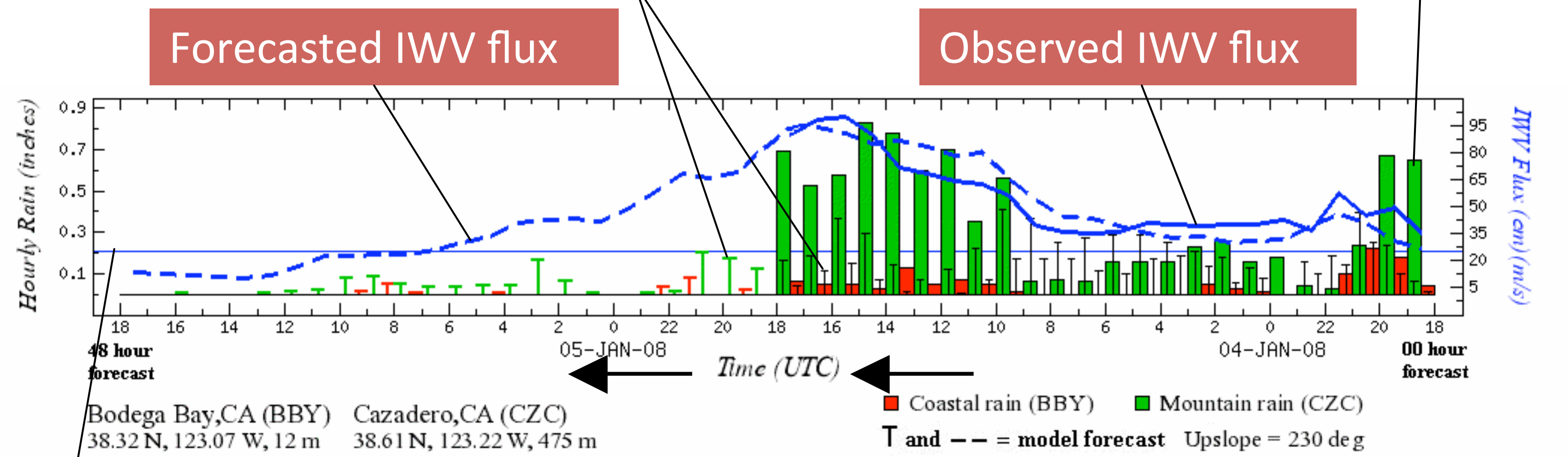
The middle panel displays the upslope component of the flow and the IWV



The IWV and upslope flow from the middle panel are combined to produce a bulk IWV flux, which is displayed in the bottom panel along with the coastal and mountain hourly rainfall

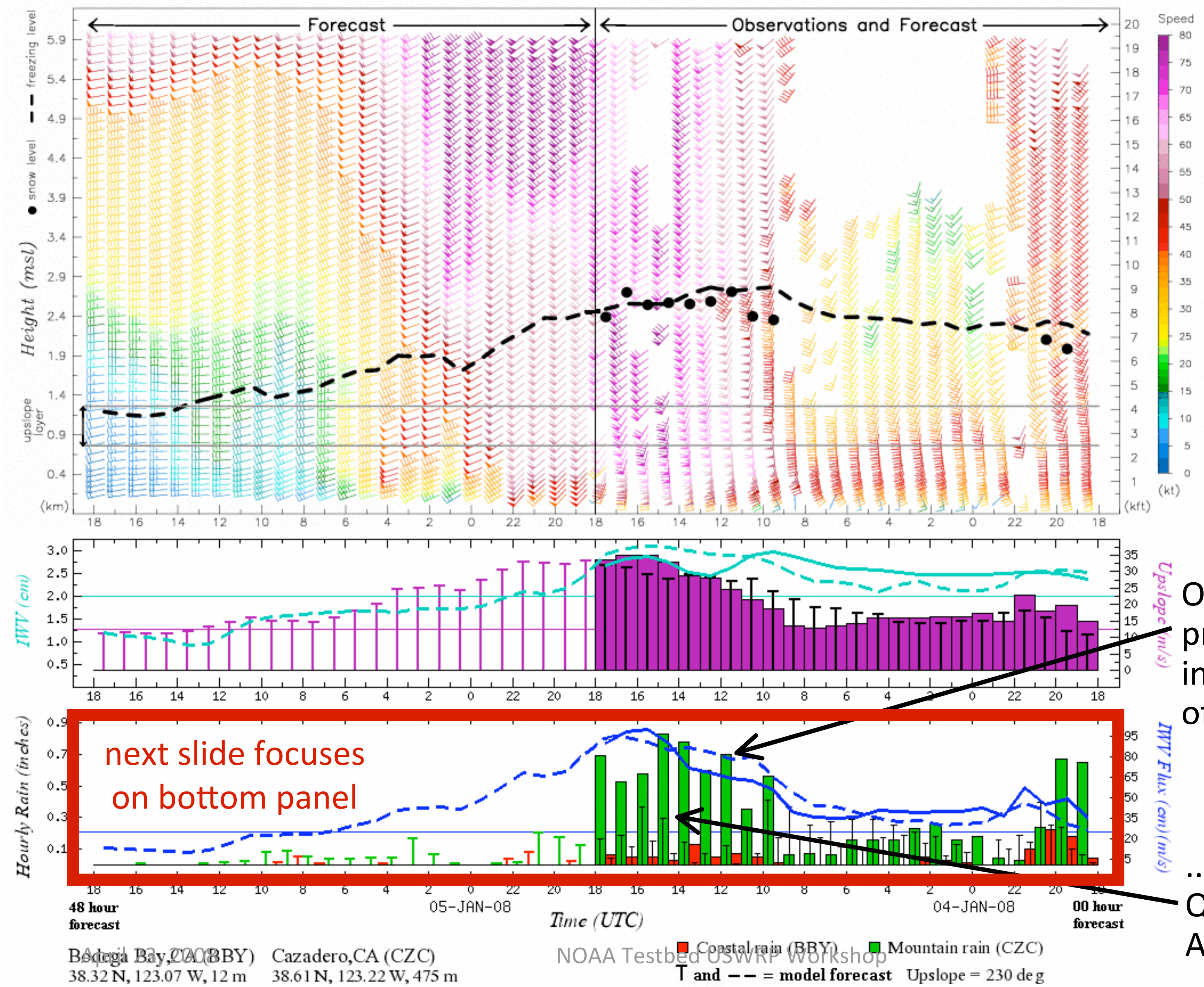
Forecasted rainfall (T posts):
Red = coastal site
Green = mountain site

Observed rainfall (bars):
Red = coastal site
Green = mountain site



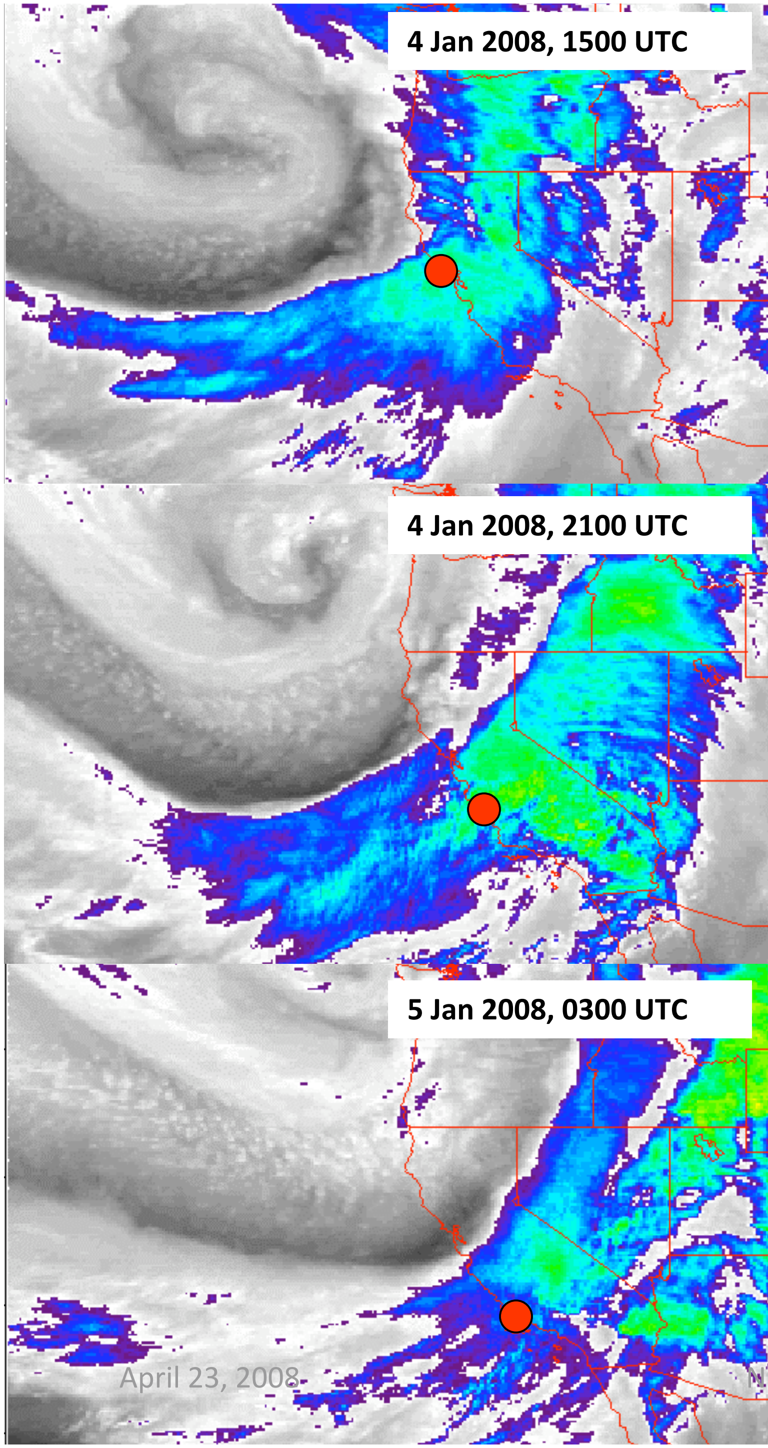
The thin blue horizontal line gives the IWV flux threshold (25 cm x m s^{-1}) determined by multiplying the IWV and upslope flow thresholds defined in the middle panel

Northern couplet: BBY & CZD

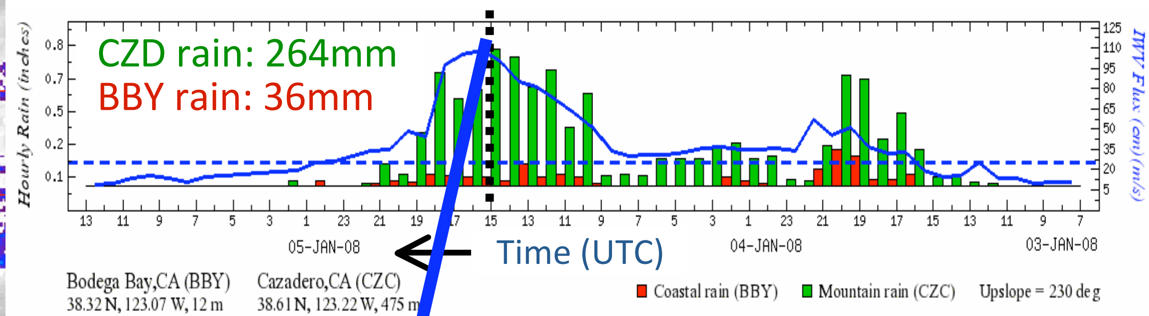


Orogr. forcing predicted well in this portion of the AR...

...but not the QPF, esp. in AR conditions.

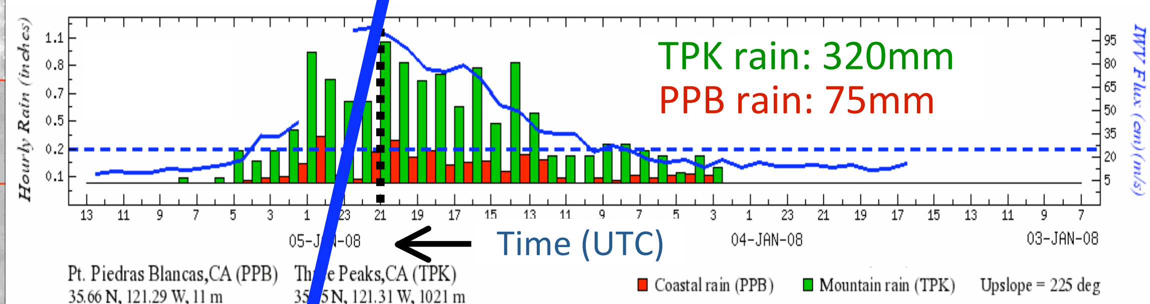


Time of max. IWV flux at BBY: 1500 UTC 4-Jan-08



Max. IWV flux in AR highly correlated with max. mountain rainfall at each site

Time of max. IWV flux at PPB: 2100 UTC 4-Jan-08



AR Propagation: ~12 m s^{-1}.

½-day lead time for SoCal

Time of max. IWV flux at GLA: 0300 UTC 5-Jan-08